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ABSTRACT

This critical review synthesizes information related to the use of the laboratory in science programs. Several approaches to the use and/or role of the laboratory in science teaching are presented, including historical and research perspectives, opinion statements, a review of current research, and suggestions for future research. Concluding remarks, speculations, and recommendations also are made by the author about research related to the role of the science laboratory. (CS)

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A CRITICAL REVIEW OF THE ROLE OF THE LABORATORY IN SCIENCE TEACHING

December 1980

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From time to time concerns re-emerge in the science education community. In the present circumstances of reduced funding for education, science teachers are often asked to defend the continued use of the laboratory as an instructional approach. The ERIC Clearinghouse for Science, Mathematics, and Environmental Education has received requests for assistance in locating information which may be used as a basis for studying the problem. This critical review is produced in an attempt to synthesize information related to the use of the laboratory in science programs.

Your comments and suggestions for future publications are encouraged.

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INTRODUCTION

In 1978, the National Science Teachers Association published the first volume in a proposed series entitled What Research Says to the Science Teacher, and edited by Mary Budd Rowe. This project, funded by the ERIC Clearinghouse for Science, Mathematics and Environmental Education, was designed as a response to the pressure for educational accountability. It was intended to help science teachers become aware of relevant educational research and to encourage them to become involved in research. What Research Says. . . was produced to bring to the attention of science teachers research findings that would help them as practicing teachers and to identify kinds of research that need to be done.

Six areas of concern to both science teachers and science education researchers were included in volume I. One of these areas was the role of the laboratory in secondary school science programs, reviewed by Gary C. Bates (1978). Bates concluded his review of 82 studies with the comment ". . .for the answer has not yet been conclusively found. . ." to the question: What does the laboratory accomplish that could not be accomplished as well by less expensive and less time-consuming alternatives?" (p. 75).

Such a conclusion is of little comfort or assistance to a science teacher working in a school system that is coping with rising inflation and decreased school revenue. If educational research does not provide support for the role of the laboratory in science teaching, should the laboratory be replaced by some other instructional method considered more efficient in terms of time; less costly in terms of equipment, supplies, and facilities; less administratively burdensome in terms of both teacher and student scheduling; and more promising in terms of student achievement gains? This present review has been produced as yet another look at the role of the laboratory in science teaching.

The Scope of the 1980 Review

The fact that yet another review has been produced in no way should be taken to indicate that the one written by Gary Bates was unsatisfactory. This present review is broader in scope in that the Bates review was focused solely on secondary school science research. This 1980 review includes research at the elementary, secondary, and college levels.

It differs also in that additional research reviews were analyzed to gain a historical perspective - both of research related to the science laboratory and of the use of the laboratory as a teaching method in science.

Sources Reviewed

Some of the materials reviewed were identified through a computer search of the ERIC data base and include publications announced in both Resources in Education and Current Index to Journals in Education. Also reviewed were the Curtis Digest series, both the three volumes produced by Francis D. Curtis and the three companion volumes produced by persons associated with Teachers College (Boenig, 1969; Swift, 1969; Lawlor, 1970.) Additional related literature included relevant chapters from issues of the Review of Educational Research on science education as a special topic; reviews produced by personnel from the U.S. Office of Education; the annual reviews of research produced by the ERIC Clearinghouse for Science, Mathematics, and Environmental Education in cooperation with the National Association for Research in Science Teaching; as well as reviews completed by individuals and published as journal articles or presented as papers at professional association meetings.

In addition, the yearbooks of the National Society for the Study of Education (NSSE) which were devoted to science education were also reviewed to identify opinion statements about the role of the science laboratory, as were materials produced in connection with the science curriculum improvement project efforts funded primarily by the National Science Foundation. A manual search of Dissertation Abstracts for the period of 1960-1978 was also conducted to identify doctoral dissertations which might not have appeared in print as journal articles or research reports.

Journal articles and other documents were read in their entirety. In some instances doctoral dissertations were reviewed in microfilm form or in paper copy but, for the most part, information related to doctoral research came from the abstracts of the research as reported in Dissertation Abstracts International.

Format of the Review

The information presented in this review will be directed toward the consideration of two major topics that seem to appear in much of the literature related to use of the laboratory in science teaching: why the laboratory should be used in science, and goals or objectives this use is hoped to accomplish.

Related to the first topic is a large amount of literature which can best be characterized as opinion-based rather than research-based. Tied to these opinions or assumptions are the goals and objectives science educators consider desirable for science teaching and learning. Research studies on the role of the laboratory are focused on how well, if at all, these goals are attained by students as a result of experiences in the science laboratory.

It seems logical, therefore, to look at the development of the laboratory as an instructional method in science and then to consider what leaders in science education have said about the use of the laboratory in science at various periods of time. This should provide some insight about changes, if any, in laboratory use as well as reasons given for this use.

Frequently educational practices become commonly used and then we begin to conduct research to justify their use, rather than conducting research to determine if the practice should be widely disseminated before the dissemination begins. To conform with reality, the discussion of research related to the laboratory will follow the description of the development of the laboratory as a science teaching method.

Trends identifed from annual and topical reviews of research will be discussed. Research reports from these reviews, as well as from journal articles and abstracts of doctoral dissertations, will be analyzed. The concluding section will be focused on the identification of potential research topics, if any exist. Welch, writing in the review of research in science education focused on the secondary school level for the years 1968-69 and discussing a research study comparing the use of the laboratory with other methods of instruction, introduced the study with the phrase ". . .in what should probably be the last study of this type. . ." (Welch, 1971a, p. 38). And, it may be that the role of the laboratory has been sufficiently researched, although the science education community may be less than happy with the data which have resulted.

THE USE OF THE LABORATORY IN SCIENCE TEACHING: A HISTORICAL PERSPECTIVE

Information on the development of the science laboratory as a method of instruction came from several sources (Fay, 1931; Hurd, 1961; Johnson, 1977; Moyer, 1976; Rosen, 1954; Woodburn and Obourn, 1965). In looking at changes in science teaching that have occurred over the years, it is a good idea to keep in mind three points that seem to summarize the history of education: society keeps changing, schools lag behind changing social needs, and periodically we have "new" schools. Forces that produce change are primarily those in democratic philosophy (Callahan and Clark, 1977).

Hurd, in his discussion of biological education in American schools 1890-1960, identified eight types of events that influenced education during this period: (1) the closing of the frontier and the beginning of urban industrial society, (2) growth of scientific professions and major contributions to scientific theory, (3) the acceleration of scientific and technological developments catalyzed by World War I, (4) the development of the industrial research laboratory, (5) the rise of automation and the economic depression of the 1930's, (6) World War II and the atomic age, (7) engineering and scientific advancements that symbolized the space age, and (8) the explosion of scientific knowledge during the decade of 1950-60 (1961, p. 6).

Johnson, writing of changes in science education 1850-1950, cited nine "revolutionary" changes: (1) the object method, (2) attempts to control curricula, (3) science teachers organize and respond, (4) the nature study movement, (5) the general science movement, (6) foundation support for curricular change, (7) toward principles and major generalizations, (8) the human needs emphasis, and (9) the nurture of future scientists (1977, pp. 119-151).

Hurd's perspective relates to that of the changes in society that influenced education while Johnson's discussion emphasized changes that took place in science education in response to events and pressures. Woodburn and Obourn looked at science education over a period of time from the perspective of changes in school curricula, treating each science separately (1965, pp. 165-260). The articles by Rosen (1954) and by Moyer (1976) relate to a much narrower topic in science eduation history: the physics laboratory. Fay (1931) reviewed chemistry teaching in American high schools from 1800-1930.

The Emergence of the Laboratory in Science Teaching

Points of view on the purposes of education vary. Part of this variation is philosophical. Because of varying philosophies and points of view, what people consider to be the function of the school varies. Some views of this function may be: (1) to transmit the culture, (2) to transform the culture, (3) to promote individual development, or (4) to attempt to take an eclectic position combining the first three views.

These differing points of view, combined with the cycle of social change-school response to social pressures resulting in changed schools, are evident in the teaching of science in American schools over the years. Emphases and trends change over time, only to reappear in modified form as social and economic conditions influence education.

1750-1880. There is no evidence that science was a part of the curriculum in American schools during the era of the Latin Grammar schools. However, the curriculum in the academies established for non-college-bound students did include natural philosophy (a forerunner to physics) and astronomy. Science teaching had three aims: descriptive, utilitarian, and religious. Would-be ministers studied science to understand God; would-be merchants, to understand the goods they sold.

In some science courses today, the utilitarian aspect is still evident, with an emphasis on the practical applications of science. The descriptive emphasis also persists. The religious emphasis is less common.

Toward the end of this period, two pressures influenced education: pressure toward standardization among schools and pressure for free, universal secondary education based on broader curricular foundations than academies provided. Pressure for standardization led to restriction of course offerings. Pressure for universal education led to variation based on individual and local needs.

1880-1910. During this period there was a shift in the aims of the schools. Utilitarian and religious emphases gave way to training of the mind -- drill on factual information = memory training. Faculty psychology and the doctrine of formal discipline were popular.

Faculty psychology, although using psychological language, is really a philosophy of education with a history tracing back to the Middle Ages (Good, 1956, p. 317). Mental faculties are supposed to be such capacities as the power to remember or to think or to "see a point." Faculty psychology was the dominant philosophy of education until the middle of the 19th century and for some time after. People believed that as faculties developed, the objective powers were the first, followed by the powers of forming images and building an inner world, and eventually, as the individual approached maturity, the capacity to deal with abstract truths and higher generalizations developed.

High school chemistry teaching was also influenced by the aim of mental discipline for which the laboratory method was unnecessary (Fay, 1931, p. 1547). Chemistry textbooks were written by college professors, with the content organized logically rather than psychologically. It was also the influence of college faculty that resulted in the use of the laboratory method in high school chemistry classes. College professors in America were in turn influenced by European methods of science teaching, with Wolcott Gibbs of Harvard bringing to American education von Liege's emphasis on research. Chemistry was the first high school science course to make any extensive use of the laboratory method (Fay, 1931, pp. 1548-1949).

By 1880, laboratory equipment was installed in some high schools. Chemistry instruction also changed in that chemistry textbook content emphasized information on laws and theories. Fay wrote "By the end of the century the concept of mental discipline overshadowed every other objective in high school chemistry; the laboratory in many cases almost entirely superseded the textbook. . ." (p. 1550).

Many people went to Germany to study physics and brought back with them the German emphasis on "no final truth" and the use of the laboratory for impersonal observations of factual phenomena (Rosen, 1954). These ideas seemed to combine well with the emphasis on object teaching as popularized by the Oswego Normal School. Object teaching was intended to develop accuracy of observation and perception, helping pupils to form correct concepts and developing skill in reasoning. Materials and lessons were to be adapted to the stages of children's mental development (Good, 1956, p. 217).

Object teaching was criticized as consisting of lessons lacking in connection and for failure of an overall plan. The pressures for standardization of curricula were, in part, responsible for the decline of object teaching. It may also have taken on a more acceptable form as nature study. Some of the early ideas of nature study still exist today in ecology and out-door education.

While nature study and object teaching were in vogue in elementary education, secondary education was influenced by college domination. Emphasis was placed on preparation for college, with little consideration for the interests and needs of the learner. College domination and pressures for standardization both influenced secondary school science teaching.

For example, in 1878 a questionnaire was sent to a large sample of schools to determine whether they offered a physics course with laboratory work and to determine the length of this course. Only 11 of the 607 respondents used the laboratory in their physics classes and only 4 of the 11 offered the course for an academic year. Frank Clark, of the University of Cincinnati, who analyzed these data for the United States Commissioner of Education, suggested that laboratory work should be an "essential and prominent feature" of every course in the physical sciences, with the goal of training the faculty of observation and teaching pupils the experimental method of solving problems (Moyer, 1976, pp. 96-97). Moyer suggested that Clark's point of view was probably influenced by his background in chemistry, a science in which the instructional laboratory was fairly well established by 1880.

A second study was commissioned in 1883 in an attempt to upgrade secondary school physics programs and to deal with what was considered as undesirable duplication (and diversity) in high schools, normal schools, colleges, and unversities. There were 70 respondents to this questionnaire and they were in favor of standardization of course content. Another objective of this survey was to determine the aims of physics teaching. Twenty-six of 32 high school physics teachers responding thought the high school physics course should be experimental, with experiments being largely qualitative. Laboratory work was favored but little tried.

Charles Wead, a faculty member at the University of Michigan who was directing the 1883 study, decided to develop a list of 47 "fundamental experiments that should never be omitted in a high school course" (Moyer, 1976, p. 98). Wead frequently cited a high school physics textbook that emphasized student experiments. The author of this textbook, Alfred Gage, justified the use of experiments in physics because of the success of the introduction of student laboratory work in chemistry during the past 20 year period (1862-1882). Gage reasoned that if laboratory work made chemistry more interesting to students, the same cause and effect relationship should hold for high school physics (Moyer, 1976, p. 98).

When Harvard admission standards were revised in 1886, a decision was made to create a laboratory requirement in physics for secondary school students who wished to enroll at Harvard. This may be interpreted as evidence both of college domination and of the move toward standardization of the secondary school curriculum. Edwin Hall and his colleagues were asked to specify what this requirment involved. They decided the laboratory course should have at least 40 experiments and should cover mechanics, sound, light, heat, and electricty. This turned out to provide too much latitude in the choice of experiments and it was decided to prepare detailed descriptions of the 40 experiments the physics course should include. This effort eventually led to the descriptive list which was revised and lengthened, in 1897, to include 61 experiments grouped into mechanics and hydrostatics, light, mechanics, heat, sound, and electricity and magnetism (Moyer, 1976, p. 99).

Hall maintained that laboratory instruction was essential because it provided training in observation, supplied detailed information, and aroused pupils' interest--outcomes of laboratory instruction which are still espoused and investigated in the 1970's.

While the move toward standardization of curriculum was under way, other changes were taking place in the American schools which had implications for science teaching. Enrollments were increasing. More and more immigrants were coming to America. Prior to 1880, most immigrants were from northwestern Europe. These people pushed inland for farming land. During the 1880's, southern and eastern European countries provided immigrants. These differed from their predecessors in several ways. They tended to remain in eastern cities, and they also differed in religion, language, and customs.

While the laboratory was being added to high school physics, biology in the secondary school was studied relative to its function and purpose. Prior to 1890, practically all secondary school students went to college because only 3.8% of high-school-aged pupils were enrolled in secondary schools. Hurd characterized the 1890-1900 period in biological education as one dominated by the use of the laboratory manual, providing some indication that laboratory activities had been taking place in biology for a longer period of time than in chemistry and physics. Growth of laboratory work received its strongest support, according to Hurd, from the mental discipline theory rather than from any biological justification. Laboratory work was seen, in all the sciences, as an ideal procedure for training and exercising those faculties of the mind devoted to observation, will power, and memory until this idea was rejected after the turn of the century (Hurd, 1961, p. 18).

The influence of faculty psychology, with its emphasis on mental discipline, was also evident in physics. G. Stanley Hall, an educator and psychologist, criticized the overemphasis on exacting laboratory work in physics and hypothesized that this emphasis had in part caused the decline in physics enrollment (from 25% to 20% of the high school pupils eligible to take the course). Hall said the physics course did not consider the nature, needs, and interests of high school students; the laboratory experiments and textbooks were too quantitative and were too concerned with precise measurements. Hall's criticisms were rebutted with the argument that quantitative experiments were the best means for training the mental faculties and for cultivating the powers of observation (Moyer, 1976, p. 102).

The National Education Association (NEA) continued to be involved in the problems of lack of uniformity of high school curricula and in college admission standards. In 1893, the Committee of Ten, convened by the NEA, issued a report which called for emphasis on secondary school science education for non-college-bound students and also encouraged the use of laboratory work. In 1898 the science committee of the NEA recommended that high school science courses should contain four hours of laboratory work a week, with all laboratory periods being two hours long, and two periods of recitation-demonstration instruction (Hurd, 1961, pp. 13-14).

The emphasis on science for the non-college-bound helped to promote the development of a general biology course in the high school resulting from the unification of botany, human physiology, and zoology. It was hoped that such a course would appeal to the average student and would emphasize the scientific method and the development of problem-solving skills.

G. Stanley Hall, whose criticisms of high school physics teaching were discussed earlier in this review, was an advocate of equal opportunity for all students at the secondary level--stressing the right of all who came to school to be offered something of value. Educational psychology as expounded by Dewey, Thorndike, and Kilpatrick became popular and replaced the mental discipline emphasis. The project method, with its emphasis on student interests and experience, began to influence teaching (Hurd, 1961, p. 28).

1910-1938. During this period the reaction against college preparation as the chief function of the secondary school continued. There was some reversion in science teaching to descriptive-information, utilitarian aims. Part of this change was a result of the rapid rise in the secondary school population and the need to accommodate these pupils. Many students entered high school but did not continue to graduation. General science was developed as a ninth grade course in the hope that such a course would provide more adequate preparation for biology and general orientation to high school science. Subject matter was concentrated in the physical sciences. During the 1900-1910 decade the 6-3-3 form of school organization was set up and general science was introduced in the junior high school as a replacement for a course in physical geography. Demonstration was a primary teaching method. Science courses with a "general" emphasis attracted high school students and enrollment in general science and

biology rose while enrollments in physics, physical geography, and physiology dropped.

Even if there were more demonstration activities than laboratory work in general science, the laboratory was still in use in other science areas. In the report from the NEA's Commission on the Reorganization of Secondary Education, published in 1920, the use of the laboratory was criticized in relation to the seven cardinal principles of secondary education. The laboratory was considered to contain too many experiments designed merely to check on generalizations the student already perceived and to repeat the textbook, often data were collected as an end in themselves and were not further used, many experiments were minutely quantitative and called for refinements beyond the understandings of the pupils, the laboratory and the science classroom were separated both physically and intellectually, and notebook-making and notebook records appeared to serve no real purpose (Hurd, 1961, p. 36).

The Commission recommended that the aim of laboratory instruction in science should be to develop a consistent chain of significant ideas related to class work, with the laboratory serving to provide concrete experiences; laboratory work should precede textbook assignments, under most circumstances; laboratory work should not be an end in itself and, therefore, detailed microscope work, elaborate drawings, and excessive notebook making were not encouraged (Hurd, 1961, p. 38).

In 1932, leaders in science education produced a yearbook for the National Society for the Study of Education in which they advocated some changes in science teaching. Entitled A Program for Teaching Science, this yearbook contained a discussion of the contributions of educational research to the solution of teaching problems in the science laboratory (Chapter 7, pp. 91-108). Francis D. Curtis, who wrote this chapter, summarized the findings of studies in which the individual laboratory method of instruction was compared with the demonstration method by saying that each method offered training in certain knowledges, skills, and habits not offered by the other method (Curtis in Whipple, 1932, p. 106).

The authors of the 31st NSSE yearbook, as A Program for Teaching Science is frequently called, advocated the establishment of a K-12 science program with science teaching focused on big ideas rather than on laws and theories of pure science so that students could learn how to make interpretative generalizations. Thirty-eight generalizations were listed as being considered of such importance as to form the core of all science teaching in the public schools (Woodburn and Obourn, 1965, p. 173).

The depression years of this period also led people to question educational practices. Attention began to be focused on the individual student and his/her personal, social, and economic welfare. The major criterion for content selection was the meeting of student needs. Schools began to take over parent functions of health information and consumer education. Society demanded that the purpose of science in the high school curriculum be justified.

In addition to the 31st NSSE yearbook, other national reports produced during this period had implications for science teaching. In 1938, several publications appeared related to science teaching. One, entitled Science in General Education, was produced by a group from the Progressive Education Association. The chief contribution of this publication was the analysis of the use of reflective thinking in the solution of problems and contributions of science to broad areas of living. The use of the laboratory was advocated for its opportunities in problem solving. Also in 1938, the Educational Policies Commission of the NEA issued a goals statement advocating that American education should have a common set of goals; both elementary and secondary schools should develop programs that would fulfill the purposes of education in a democratic America.

A third 1938 publication was that of the National Association for Resaerch in Science Teaching which was a report produced by the NARST Committee on Secondary School Science. This group had sent out a questionnaire designed to identify "better" practices in secondary school science teaching. The questionnaire went only to a selected group of individuals, 79 of whom responded. Items reported received 95% agreement (or more). Those related to the science laboratory were "Laboratory work in secondary school science should be designed to teach pupils how to observe, how to come to independent conclusions on the basis of their own observations, and how to check their conclusion." (Hurd, 1961, p. 69). Respondents identified the need to use both demonstration and laboratory as instructional methods and to closely correlate classroom and laboratory work.

While individuals or groups were issuing reports, other persons were criticizing these materials, complaining that there was too much emphasis on what should be done and too little emphasis on how it should be done, even though some reports contained course outlines and sample teaching units (Hurd, 1961, p. 72). The strongest criticism of individual activity was that the student spent a large amount of time in the activity for very little educational return. Teacher demonstration appeared more economical in terms of both time and money, especially since research evidence indicated that students could learn facts by either method. As a result, some schools dropped the double laboratory period (Hurd, 1961, p. 73).

1938-1950. Hurd identified World War II and the advent of the atomic age as two major influences on the teaching of science in this period. Society began to recognize the growing importance of science in education. In 1942 a committee representing 17 scientific and science teaching societies attempted to develop a philosophy for secondary school science instruction. The committee's report, entitled Science Teaching for Better Living, was based, in part, on replies from 2,500 science teachers to a questionnaire concerned with aims of science teaching. Science should stress problems of everyday living, the committee concluded. The scientist's greatest contribution was considered to be his method and this scientific method should be applied to personal and social problems (Hurd, 1961, p. 77).

In 1947, the 46th yearbook of the National Society for the Study of Education was published. It was called Science Education in American Schools. The role of the science laboratory was considered in Chapter 4,

which was focused on issues in the teaching of science. Issues were stated in the form of questions, with question 16 being "What are the purposes of laboratory work?" The writers decry the over-use of verification in the science laboratory, writing "Performing demonstrations or individual experiments merely for the purpose of verifying facts or principles already known is rarely, if ever, justified. . ." (Henry, 1947, p. 51). "The primary purpose of experimenting is to secure evidence which may reveal answers to problems. . ." with laboratory work preceding class discussion of a topic or principle. The practice of carrying on experiments for the mere purpose of verification often emphasizes the antithesis of the scientific method." (Henry, 1947, pp. 52-53).

Question 18, "Is the observation of a demonstration experiment as effective and valuable to a pupil as his performance of that experiment?" was followed by the remark that this issue has persisted for several decades. An article by Cunningham was cited to the effect that early research supporting the demonstration method was crude and that only retention of factual information was measured. Later research, looking at other outcomes, indicated ". . .that in certain important respects the individual method is superior to the demonstration method."(Henry, 1947, p. 54).

The authors conclude that because experimentation involves learning by doing, there can be no substitute for this activity and, therefore, pupil experimentation is an essential part of good science education. They considered the conclusions of Curtis about research on the individual method vs. demonstration, as stated in the 31st NSSE yearbook, still valid.

In a later section of this yearbook, the authors stated that laboratory work was at a minimum in junior high school science and identified several factors that may account for this situation: research showing the lecture-demonstration method of instruction as superior for immediate retention, class size too large for laboratory work, and a lack of science equipment (Henry, 1947, pp. 160-163). They suggested there was a need to build a case for laboratory instruction based on the idea that laboratories provide practice in problem solving, the manipulation of apparatus, and the need for pupils to learn out-of-school uses of the scientific method (Henry, 1947, p. 164).

Concerns for the school science laboratory were again evident in a section of Chapter 14 on "Special Problems of Science Teaching at the Secondary Level." In a subsection of this chapter, "The Role of the Laboratory in Teaching Science," the authors emphasized the need to avoid cookbook-type laboratories. Instead, the laboratory should provide pupils practice in raising and defining worthwhile problems, with laboratory activities conducted so that pupils learn the meaning and use of controls in experimentation and gain practice in analyzing data from problem situations so they learn to test hypotheses and interpret data. The authors stressed the need to maintain the proper balance between teacher guidance and student exploration. They dealt with the demonstration method by conceding that it is time-saving and a less expensive way of completing laboratory activities, but suggested that it be used mainly in problem-solving situations to challenge pupils rather than to illustrate the textbook (Henry, 1947, pp. 236-238).

Hurd characterized the latter part of this time period as one in which

> The importance of laboratory work with experience in observation and experimentation was regarded as self-evident in science teaching. . . Experimentation develops skills and coordination in manipulation; trains the powers of observation; and provides opportunities for developing resourcefulness in the use of physical materials and instruments. Individual laboratory work with its active participation is to be desired over passive observation. (Hurd, 1961, p. 93)

He also said that the question of teaching secondary school science as science for the scientist or for the citizen was never clearly answered (Hurd, 1961, p. 105).

1950-1970. In 1950 the National Science Foundation was established, with its major function that of improving education in the sciences. To quote the act of Congress that established NSF, the foundation was designed ". . .to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." (Woodburn and Obourn, 1965, p. 175). Again, social change led to the time when a federal agency was created to become involved in the development of science courses and their administration.

Hurd described the 1950-1960 period as one of a crisis in science education and reappraisal, identifying such factors as the accelerated growth of science and technology following World War II, the increase in scientific knowledge, the fact that more than 70% of all American youth were in school and more were now considering higher education, and a concern that the gifted and talented high school students were not being intellectually challenged by their education. Enrollments in science increased but the number of science teachers decreased. In 1958 the National Defense Education Act made it possible for schools to purchase science laboratory equipment (Hurd, 1961, pp. 108-110).

The third NSSE yearbook, Rethinking Science Education, was produced in 1960 as the 59th yearbook of the Society. Its authors attempted to forecast "oncoming objectives" of science education. Although the statement "there is no one method of teaching science that can be considered unquestionably superior to all others" appeared in several places in this yearbook, there was continued emphasis on laboratory teaching. In Chapter 13, "Facilities, Equipment, and Instructional Materials for the Science Program," sub-heading: "Equipment for Science-Teaching," the place and function of laboratory teaching and types of laboratory-teaching equipment and procedures were discussed. The authors stated, "All science-teaching is, to some extent, laboratory teaching. Children (and grownups, too), when they get the chance seem naturally to want to try out things. . .Every classroom where science is taught should be a place for experimentation. . ." (Henry, 1960, p. 246).

The authors stated that every laboratory exercise should have a clear-cut educational purpose and identified five: (1) to add reality to textbook material, (2) to develop first-hand familiarity with tools,

materials, and techniques of science; (3) to allow students to demonstrate to themselves something they already know to be true; (4) to give students opportunities to pit their laboratory skills against par in seeking experimental answers; and (5) to create opportunities wherein students predict events or circumstances and then design experiments to test the accuracy of their predictions. The fifth purpose was considered the most cogent reason for using science laboratory activities (Henry, 1960, pp. 245-247).

In Chapter 18, the yearbook authors, in considering problems and issues in science education, dealt with the question that Hurd said was not clearly answered in the early 1950's: science for the scientist or for the citizen? They asked the questions "Should the objectives of science teaching be the same for all students? for the potential scientist vs. the layman? Should science be taught for its own sake or for social usefulness? What emphasis should be placed on technology as opposed to pure science?" They conceded that critics say that science teaching should be oriented toward the intellectual processes (creative or intuitive thinking) and suggested that the purposes of science teaching need to be clarified. They also considered the roles that the scientist, the science teacher, the science educator, and the layman should play in developing curriculum changes in science. In addition, they raised the question of whether there should be a nationwide curriculum in science and, if so, who should serve on the planning committee?

In another section, focused on the problems of teaching in science education, the laboratory was again scrutinized. The authors concluded that

> Changing conceptions of the values and purposes of science-teaching have tended toward an increasing emphasis upon laboratory work. The nature of the scientific enterprise is found in the methods by which problems are attacked. Therefore, more attention should be directed to the processes or methods of seeking answers in the laboratory rather than putting so much stress on finding exact answers. More time should be spent by students in developing insights as to how data may be processed and predictions made from them. (Henry, 1960, p. 334)

In 1963 the Office of Scientific Personnel (OSP) of the National Academy of Sciences produced a booklet entitled "Guidelines for Development of Programs in Science Instruction." The authors of this publication identified three basic elements to be considered in planning for the laboratory: the student, the teacher, and the facilities and equipment. They wrote,

> . . . the function (of the laboratory) has far more significance than the practical application of the lessons learned. . . One of the important functions of the laboratory is the deepening of a student's understanding that scientific and technological concepts and applications are closely related to his own natural environment. (OSP, 1963, p. 1)

In the laboratory students should be able to observe natural phenomena with a discerning eye, make measurements and analyze data recorded, and

engage in free-ranging investigations that do not necessarily have a predetermined end (OSP, 1963, p. 1).

The writers suggested that widespread misconception of the nature of science led to laboratory assignments that were merely exercises designed to verify laws or rules while others saw the laboratory as showing the practical side of science, divorced from and having less prestige than the theoretical parts of a science course. The essential nature of science - as a continually evolving enterprise of the human mind - depends upon careful experimentation and upon more and more sophisticated work in the laboratory (OSP, 1963, p. 3).

> In the laboratory the student can be taught more readily to be discriminating in observation, to evaluate evidence or data, and to sense the importance of care and skill in the taking of measurements.
>
> In the laboratory the student should develop the contemporary view of the limitations of measurement, of inherent uncertainty, of the possibliity of achieving only better approximations as to what will ultimately be accepted as most likely values. But with this must be coupled an appreciation for the continuing utility of such measurements, because one can know the limits of their applicability or of their exactness. Similarly, the continuing usefulness of certain scientific 'laws' can be demonstrated through application even if they fail to account for all phenomena, for example, in the microscopic domain. (OSP, 1963, pp. 3-4)

The authors consider that studies on learning processes have implications for the role of the laboratory in science teaching. In terms of transfer of training, the laboratory can provide students with an understanding of procedures for scientific investigation, including control of certain variables, careful observation and recording of data, and the development of conclusions. In terms of concepts of readiness, motivation, and structure, work in the laboratory must take into account differences in the level of student development, environment, and experience. "An emotionally satisfying, successful learning experience is one of the strongest incentives for continued learning. It is here that the laboratory holds great potential. . ." (OSP, 1963, pp. 4-6).

The authors emphasized the need to provide initial laboratory experiences or to build on previous ones which result in student involvement in an emotionally and intellectually satisfying manner (OSP, 1963, p. 7).

Teachers need to know how material should be presented as well as what students should learn. ". . . a preoccupation with the material and physical elements of a laboratory will not guarantee effective learning. The attitude, understanding, the knowledge, and the motivation of the teacher are central. However, even the best teacher must have facilities and equipment to teach effectively" (OSP, 1963, pp. 12-13). Again, (p. 38) "The most important element in any program of laboratory science instruction is a well-prepared teacher."

Publications seldom appear in printed form without a lengthy interval devoted to conceptualization, research and/or literature review, writing, and editing. Those publications resulting from committee work or from the efforts of a number of authors probably involve more time in production than do others written by one person or by a limited number of individuals. Usually committee-developed publications involve an initial meeting or series of meetings to get the problem identified, and may involve additional meetings to react to the work in progress.

Because this is the way things appear to happen, work was probably underway on the 59th NSSE yearbook in which future objectives of science education were forecast while other individuals were involved in science course improvement project work funded, for the most part, by the National Science Foundation (NSF). The development of curriculum materials by the Physical Sciences Study Committee (PSSC), by the Biological Sciences Curriculum Study Committee (BSCS), and by other groups at both elementary and secondary levels has been well documented in other publications and will not be discussed here.

However, some discussion of the factors that caused these curriculum reforms to take place does appear relevant. Again we need to refer to the three-stage model from the history of education:

society keeps changing,
schools lag behind changing social needs,
so -- periodically --
we have new schools.

Prior to National Science Foundation involvement in science curriculum reform, forces existed that were pressing for such reform: (1) the need for more and better scientific and technical manpower, (2) the need for better science education for talented students, (3) the idea that better education equals better economy, and (4) the increasing accumulation of knowledge, both in depth and amount.

Although this review focuses on the role of the laboratory in science teaching, it would be less than realistic to ignore the role of the textbook in science curriculum. For some schools and teachers, the textbook is the curriculum. Reasons for this situation vary. Curriculum development is not an easy process and teacher education preservice programs seldom include experiences aimed at helping in-service teachers feel comfortable with this task. It is a time-consuming task and, to be done well, necessitates that the persons involved be well equipped both in up-to-date content and instructional methodology.

Therefore, the role of the textbook in science teaching is an important one. Numerous authors and committees have decried laboratory activities designed to verify the textbook. Now textbooks also deserve some consideration. Mayer, in the third edition of the Biology Teacher's Handbook (1978), focused on biology textbooks but his remarks apply equally well to those in other science courses.

Biology textbooks in the 1800's and the early 1900's "contained a mass of disconnected facts and elementary generalizations that were presented

almost entirely as description. . ." (Mayer, 1978, p. 3). However, these books were written by scientists or their colleagues who knew the state of the discipline. Mayer commented that in 1915 more than 50% of the authors of high school textbooks were listed in American Men of Science. By 1955, this number was less that 10% (1978, p. 3).

The years 1929-1957 were ones in which modifications of the conventional science textbook took place. These modifications reflected the concern for the growing school population with its diversity of abilities, interests, backgrounds, and intentions of secondary school students (Mayer, 1978, p. 4). Emphasis changed from that of disciplinary content and the knowledge required for admission to college to more emphasis on what could readily be taught and the relationship between secondary school science textbooks and the working scientist was lost. Textbooks reflected the pressures within and without the educational system rather than the current state of a science discipline. Many were written by staff editors of publishing companies who tailored their efforts to the type of textbook the marketing staff indicated would sell. Special interest groups also exerted pressures on publishers to include, or exclude, materials that would make a textbook more salable to their communities.

In the mid-1950's there was dissatisfaction with American education in general and secondary school science education in particular. The plea was not for a return to the college-preparatory emphasis of curriculum materials in the 1910's but for information that reflected the current state of science (Mayer, 1978, pp. 4-6).

Lee and Peterson reported seven criticisms of traditional high school biology courses in the 1960's: (1) they represented little of the science of biology, (2) they were out of date in terms of current theories and knowledge, (3) they were fragmented and lacked logical coherence, (4) they did not present biology as a discipline, (5) they forced memorization rather than requiring understanding, (6) laboratory work failed to portray the investigative nature of biology, and (7) they were taught more as a dogma than as an on-going science (1967, p. 67). Laboratory activities were illustrative rather than experimental and quantitative.

These criticisms applied to sciences other than biology. Rosen, in his review of the history of the physics laboratory which was published in 1954, reported that he stopped discussing the laboratory as it existed after 1910 because, even though some changes in practice had taken place, ". . .theory behind the format of the high school laboratory work seems to have undergone little further development" (1954, p. 194).

The NSF-funded curriculum projects involved an emphasis on student investgation and inquiry (or enquiry). Joseph J. Schwab's publication "The Teaching of Science as Enquiry" in The Teaching of Science (1964) was an influential one. Schwab deplored the teaching of science as dogma. He described science teaching practices as those designed to cause pupils to regard science as a rhetoric of conclusions rather than as fluid enquiry, to accept the tentative in science as certain, and to consider the doubtful as undoubted. Science was, Schwab wrote, ". . .exhibited as a process exclusively of verification . . ."(Schwab, 1964, p. 29).

Schwab described factors affecting the curriculum as composed of four clusters: (1) "milieu" factors--needs, demands, and conditions which social structures impose upon their members, (2) "learner" factors, (3) ephemeral and perennial characteristics of teachers or the teaching process, and (4) subject matter factors. Schwab considered that there were perennial projections and ephemeral conditions affecting each of these four clusters, so there were really eight sets of factors working on the curriculum.

In the 1950's and 60's the most powerful force on the science curriculum came from the milieu cluster: the need for scientists, the competences required of political leadership, and the need for a scientifically literate public which would support science.

Schwab considered that the science laboratory could easily be converted to enquiry if some changes were made. A substantial amount of work in the laboratory should lead rather than lag behind the classroom phase of science teaching. The demonstrative function of the laboratory should be subordinated to two other functions -- to provide tangible experience of some of the problems dealt with, and of the difficulty of acquiring data. The illustration of conclusions should be replaced by the illustration of problems. The laboratory also should provide occasions for and invitations to the conduct of miniature but exemplary programs of enquiry. In both instances, the laboratory work should lead the classroom.

An adequately inquiring curriculum in science, according to Schwab, needs to have a substantial component of doubt, although publishers and teachers do not like to have this in science textbooks. Because standardized and widely used examinations play an important part in determining curriculum, a significant modification of existing texts and examinations was needed.

Schwab said that teaching and learning skills for enquiry are not common in the schools; students seldom take an active role in learning. Therefore, a science teacher's first and major responsibility should be to help students learn to learn for themselves -- to know what questions to ask of a report of enquiry, when to ask them, and where to find the answers. Students learn this skill by doing, according Schwab. Teachers also need to be skilled in the art of conducting a discussion of the type that promotes enquiry. Teachers need to avoid having students do research and then not deal with the problem of interpreting data.

Science course improvement projects at both elementary and secondary levels reflect some of the points Schwab stressed in his paper. These projects may be characterized as discipline-centered reforms, designed in large part to meet the needs of bright, science-oriented students. In using the curriculum materials students were expected to explore and discover rather than to memorize. The laboratory became the context for giving students insights into the role played by experiment in uncovering new knowledge rather than being made up of cookbook exercises. The emphasis was on scientific inquiry, both as a noun and a verb. Because scientists were involved in the curriculum reforms, these materials presented a more authentic picture of scientific disciplines than textbooks had done for several decades.

Did the use of the laboratory as an instructional method really change in keeping with this emphasis? If it did, students should have been involved in discovering for themselves rather than in completing activities designed to illustrate, describe, or verify. One method of determining what takes place during the laboratory period is that of conducting research. Some science education research taking place in classrooms and laboratories is of the observational variety. Frequently what is observed is the classroom interaction, focusing primarily on teacher and student verbal behaviors. In a few instances anthropological research has been done in science classrooms, particularly as a part of the Case Studies funded by the National Science Foundation and discussed in a later section of this review.

A more common approach to classroom research has been of the comparative variety in which students receiving method A are compared with similar students receiving method B. Frequently one of these methods is referred to as the "traditional" approach to the instruction in science. The reader is often left to his/her own devices in attempting to determine just what took place in the traditional approach, even if the experimental treatment is described in detail (which does not always occur!).

The next section of this review is devoted to a discussion of research on the role of the laboratory in science teaching as this was identified from a collection of reviews of research, as well as from individual research studies.

THE ROLE OF THE LABORATORY IN SCIENCE TEACHING: A RESEARCH PERSPECTIVE

A number of research reviews were studied in an attempt to identify trends in science education research related to the use of the laboratory as an instructional method in science. These reviews included the three produced by Francis D. Curtis (1931, 1931, 1938) as well as the three companion volumes produced by Boenig (1969), Swift (1969), and Lawlor (1970). In addition, reviews published in the journal Science Education, as well as in special publications produced by personnel in the U. S. Office of Education, were analyzed. The USOE reviews were done in cooperation with the National Association for Research in Science Teaching. A more recent series of cooperatively produced reviews of research is that of the National Association for Research in Science Teaching and the ERIC Clearinghouse for Science, Mathematics, and Environmental Education. These reviews, spanning 1963-1979, were included in the analysis, as were issues of the Review of Educational Research which were devoted to science education. Additional reviews by individuals or persons at a specific college or university include those by Blick (no date), who reviewed research in science education for the years 1937-1943 and followed the pattern of the Curtis Digests; Mepplink (no date) whose master's thesis was an annotated bibliography of science education research published during 1938-1960; a review completed by Lee and some colleagues at The University of Texas (1965) which focused on research studies in college science from July 1963 to July 1964; a review by T. Wayne Taylor et al. covering research in secondary school science for the years 1963-1966; and an article by Willard Jacobson (1974) entitled "Forty Years of Research in Science Education."

Research on the Laboratory, 1900-1950

Francis D. Curtis, who was responsible for the early reviews of research in science education, published an article in The Science Teacher in 1950 in which he made a plea for the retention of individual laboratory work. This article is of interest for several reasons. It was written about science education research but directed to classroom teachers rather than to science education researchers. Also, it provided an overview of the problem as seen by an individual who had been involved in doing research as well as in reviewing it.

Curtis wrote that the idea that secondary school students should do laboratory work came from the "scientific movement" and was influenced by college practices at the turn of the century. Increased school enrollment was also a factor. Enrollment in high schools increased so rapidly that, beginning about 1902, one high school was built every day for at least 30 years. Increased numbers of students made it less than economical to do individual laboratory work, so demonstrations were substituted.

This increase in school enrollment came at about the same time as the rise of the educational research movement. People began studying the relative merits of individual laboratory and demonstration methods. In 1918, the first such science education investigation, by Wiley, was

published. In the next nine years, 13 such studies were published. Data from these studies were interpreted as indicating that the demonstration method was as effective as the individual method for learning. However, college and university teachers opposed the trend toward substantial reduction in laboratory work. Educational research was criticized for the limited number of studies, the small number of subjects involved, inadequate statistical treatment, the general lack of reporting of the techniques used, and the aims which the laboratory work was to achieve (Curtis, 1950, pp. 63-64).

In 1928 Horton's study of laboratory work, "Measurable Outcomes of Individual Laboratory Work in High School Chemistry," was well enough done to be used by the authors of the Thirty-first NSSE Yearbook to say that both demonstration and individual laboratory work should be done, in that each method supplements the other ". . .with unique and essential contributions." Curtis reported that "Horton's findings convincingly established the real values of the individual method and effectively destroyed the assumed justification for its elimination. . ." (1950, p. 64).

However, the 1930's and the Depression arrived, along with a trend to reduce science from seven to five periods per week (three recitation periods and two double laboratory periods). Administrators did not like the scheduling problems that double periods posed; teachers found it hard to integrate laboratory work with class discussions when the laboratory work had to be done at fixed periods; research did not support the use of double periods over single, for science classes; and teachers of other content areas did not like the idea that science got more time in a student's schedule (Curtis, 1950, p. 82).

Curtis also reported that the 46th NSSE Yearbook "championed" retaining the individual laboratory method in science in that learning by doing was well exemplified in the process of experimentation. However, he admitted that ". . . for at least half a century, the individual method of performing laboratory experiments has been progressively losing ground. In some courses and in many schools, it is facing complete elimination. . ." (1950, p. 82).

This 1950 article was actually a reiteration of some of the information Curtis had presented in the 31th NSSE Yearbook (1932) in which he discussed research related to laboratory work grouped under the headings of resourcefulness, reporting of laboratory exercises, laboratory drawings, correlating class work and laboratory experimentation, and the individual vs. the demonstration method of performing laboratory exercises. Additional groupings of research included performing laboratory exercises in pairs or in groups and laboratory teaching at the university level.

In chapter seven of the 31th NSSE Yearbook, Curtis identified what he considered to be the three most important objectives of laboratory work: (1) teaching the pupil to manipulate [i.e., learn by doing (which was different from knowing)]; (2) teaching the pupil to interpret experimental data; and (3) teaching the pupil the concept of the scientific method (1932, p. 100). In discussing the objectives of laboratory work, Curtis

cited a study by Horton involving high school chemistry classes, from which it was concluded that

> We need not expect individual laboratory work to assist the pupils in gaining abilities to succeed in written tests . . . If problem-solving ability and ability to do tasks in the laboratory are important, practice in doing similar tasks in the laboratory by self-direction seems to attain this end best. . .If ability to do experimentation or solve perplexities of a chemical nature is a desirable goal, practice in this experimentation - not practice in watching someone else experiment - is necessary. . . (Curtis, 1932, p. 103).

Comparing the individual laboratory method with the demonstration method, Curtis came to six conclusions, or generalizations: (1) each method offered training in certain knowledge, skills, and habits not offered by the other; (2) for economy of time and money, it was desirable to perform more laboratory exercises by the demonstration method than by the individual method; (3) at the beginning of the laboratory course, the teacher should make sufficient use of the demonstration method so pupils learn the apparatus and some accepted methods of experimentation and then should allow students to work individually; (4) the time saved by use of demonstrations should be used for some other types of learning; (5) demonstrations should be used for dangerous activities (i.e., those requiring "delicate manipulation and accurate observation" and expensive apparatus); and (6) teacher demonstrations should be used in more elementary courses or with younger or less able pupils (Curtis, 1932, p. 106).

Curtis Digests, Volume I. The research studies on which these statements were based probably came from research discussed in the first volume of the Curtis Digests (1971a). In this volume, seven studies were described that relate in some manner to the use of the science laboratory; Mayman, Wiley, Phillips, Cunningham (two studies), Kiebler, and Cooperider are cited. These researchers reported the laboratory to be " slightly superior" for permanent learning (Wiley) and purposes of delayed recall (Cooperider, Cunningham), valuable in familiarizing pupils with apparatus and methods of laboratory procedures (Phillips), and useful for sustaining interest if experiments run for more than one day (Cunningham).

Curtis Digests, Volume II (1971b). Eight laboratory research studies are discussed in the second volume of the Digests which was also first published in 1931. Johnson, Walter, Pruitt, Anibal, Knox, Horton, Nash and Phillips, and Noll were the investigators cited. Pruitt and Anibal reported that the use of the laboratory method is superior to other methods for retention of information although Anibal's findings were less positive than those of Pruitt. Knox reported the laboratory method to be slightly superior relative to knowledge and method of attack (on problems) for the "average inferior pupil" (1971b, p. 298).

Horton's research involved the study of several problems. He was interested in determining the manipulative skills and habits involved in laboratory work in high school chemistry and then in identifying the

relative importance of these skills and habits. Horton listed nine groups of skills: (1) use of the Bunsen burner and heat, (2) setting up and connecting apparatus, (3) handling glassware, (4) handling liquids, (5) handling solids, (6) handling gases, (7) measurements, (8) general laboratory habits, and (9) miscellaneous, unclassified techniques. Horton looked for corresponding items in 15 widely used laboratory manuals and developed a list of 102 items which he sent to 25 chemistry teachers to rate the desirability of developing the skill into a habit.

Horton came up with an approved list of 55 items. Thirty-five of these were chosen by 75% or more of the respondents as deserving to be taught as habits and the first three items on the list were chosen by all respondents. These were (1) twist or screw a stopper into a tube, (2) twist or screw a glass tube into a rubber stopper, and (3) smooth the ends of freshly cut glass tubing (fire polishing).

Horton then conducted a study to determine the relative values of the individual laboratory exercise and the demonstration exercise on written tests and on individual performance of certain tasks in the laboratory. Results of both written tests and the performance test favored the classes using the individual laboratory method (Horton in Curtis, 1971b, p. 305). Horton also reported a second study in which cognitive and psychomotor outcomes in chemistry were investigated. In this study, results also favored the individual laboratory method (as opposed to the demonstration method). In a third study, Horton looked at the influence of types of directions (three types) compared to teacher demonstration on three outcomes: laboratory techniques, cognitive knowledge, and ability to solve problems. This study lasted for 10 weeks of instruction. Horton reported no significant differences for any of the methods relative to achievement on the written test. Pupils favored the individual laboratory as a method of instruction, however.

In Noll's research some reading or oral recitation was substituted for laboratory work in general inorganic chemistry for college freshmen. The section having the greatest amount of laboratory work showed "fairly consistent superiority in general achievement" (Noll in Curtis, 1971b, p. 401). However, Noll reported that there were other factors involved that may have contributed to this finding.

Curtis Digests, Volume III (Curtis, 1971c). Three studies related to the laboratory were discussed in this publication (Applegarth, Duel, Payne). Only one of these was a conventional comparative study, by Payne, in which he studied first-year college chemistry classes and found "no marked differences" in the upper halves of the groups (individual laboratory vs. lecture-demonstration) but that the demonstration method was favored for the lower halves of the groups and for the whole group. Although Payne's data favored the demonstration method, students reported the laboratory was more interesting (than was the demonstration method) and helped them to remember better.

Applegarth and Duel both looked at the effects of time in the laboratory. Applegarth's data indicated that the double period for chemistry could be shortened in terms of completion of experiments without

sacrificing comprehension. Duel's research focused on college physics classes and the effect on knowledge of two hours of laboratory work as compared to no laboratory work. He found no significant differences in mean achievement.

Curtis Digests, Volume IV (Boenig, 1969). Two studies related to the laboratory were identified, and one of these is questionable in terms of inclusion in this review because nothing in the report indicates that either student group involved was engaged in laboratory activities. Barnard investigated the use of the lecture-demonstration method as compared to the problem-solving method on cognitive achievement. While it may be assumed that solving problems involves experimentation in the laboratory, this may not be the case. Anyway, Barnard reported that the problem-solving method was statistically significant for biology survey students in problem-solving situations and for the development of scientific attitudes. Johnson looked at the question of whether making detailed drawings in the zoology laboratory was of any value and concluded that the time should be spent in studying material rather than in polishing drawings.

Review of Educational Research (RER), 1930-1950. Volume 1, Issue 4, published in October, 1931, covered research for the years 1928-1930 (Breed, 1931). The authors wrote, "On the side of methods the value of laboratory work is still a subject of debate. Experimental studies indicate that the demonstration method yields better educational results than the laboratory method, and is more economical from the standpoint of time expenditure, current expense, and capital outlay"(p. 293). In Volume 1, Issue 5, Powers (1931) contributed a chapter in which he cited three investigators who did experiments in laboratory teaching and found that the demonstration method was favored over the individual laboratory method of instruction, and five others who found no significant differences in the use of the two methods in terms of tests of information. He also discussed Horton's study in which no significant differences on subject matter attainment were found but statistically significant differences were found on tests constructed to measure abilities ". . . definitely exercised in the laboratory. . ." (p. 385).

Volume 2, Issue 1, published in February, 1932, contains the information that, since 1923, 15 experiments on the high school level have been reported but

> . . .The experimental technics used are open to serious criticism. Lecture-demonstration appears to engender informational abilities when tested immediately, as well as the individual laboratory method; but when retention of information is tested some months later the differences favor consistently, but not with high statistical significance, the individual laboratory method. (Engelhart, 1932, pp. 21-22)

The author concludes, "Although most, if not all, of these experiments are subject to certain limitations, the consistency of the findings probably justified the conclusion that demonstration lectures by a skillful instructor are satisfactory substitutes for a considerable portion of the usual individual laboratory exercises" (p. 23).

No research relevant to the topic of this review was identified in the April, 1934, issue of the Review of Educational Research. The December, 1934, issue contains a citation of Payne's study of college chemistry in which students were reported to make better progress when new topics were introduced by the lecture-demonstration rather than by the laboratory.

No relevant research was found in Volume 5, Issue 1, February, 1935; Volume 7, Issue 2, April, 1937; or Volume 7, Issue 5, December, 1937--all of which focused on science education research.

Volume 8, Issue 1, February, 1938 (Powers, 1938), contained a criticism of a study by Atkins related to objectives of laboratory instruction in general biology. It was said that the study had evidence of a high degree of resourcefulness but no significant differences related to methods and that there was a weakness in evaluation. The emphasis in the study was on methods of thinking but the instruments used to measure this objective were tests on information.

In Volume 12, Issue 4, October, 1942 (Powers and Edmiston, 1942), a study was reported in which pupils who answered a series of study questions related to laboratory work had better test scores than those who wrote formal laboratory reports. The authors wrote ". . .In general the superiority of students having experimental activity programs over students having traditional programs is reported as inconclusive for science and mathematics. . ." (1942, p. 364).

In Volume 18, Issue 4, October, 1948, covering research for the period of May 1945-1948, Cunningham's review is cited (Richardson and Barnard, p. 333). Cunningham reviewed 37 studies (6 doctoral dissertations, 18 master's theses, and 13 articles) dealing with the problem of the lecture-demonstration vs. the laboratory - and concluded that the data did not conclusively favor one method over the other. The desirability of the method to be used should be determined by the objectives sought and the conditions under which the course was taught (p. 333). In chapter six of this issue, Burnett and Gragg discussed teacher education in science and cited an article by Richardson on the problems faced in the education of science teachers. One criticism of teacher preparation was that teachers had a very limited conception of the function of the laboratory in the learning situation in science (p. 364).

Research on the Laboratory, 1950-1970

Curtis Digests, Volume V (Swift, 1969). This publication covers the years 1948-1952 and overlaps the arbitrary division in this review. However, the studies cited which related to the laboratory were published in the 1950's. Boeck looked at the inductive-deductive approach as compared with the deductive-descriptive approach in high school chemistry instruction. He found the inductive-deductive approach to be superior for knowledge of and ability to use the scientific method with accompanying scientific attitudes.

Martin's research was a status survey of high school biology teaching in the United States in 1949-1950. He reported

> Laboratory work, used in instruction in 97.7% of the schools, was performed during regularly scheduled single or double periods in 36.6% of the schools, during integrated laboratory-recitation periods in 35.2%, and with flexible scheduling in 28.2%. Small group experiments were used in 26.2% of the schools, individual laboratory work in 20.2%, pupils paired for experiments in 19.0%, teacher demonstration only in 15.5%, observations by pupils in the classroom in 5.9%, and pupil demonstrations in 2.2% . . (in Swift, 1969, p. 100).

Research by Smith was related to the laboratory in that he attempted to determine experiments desirable for a course in general science in the junior high school based on four criteria: (1) the experiment must be safe, (2) it must be simple enough to be comprehended by children in dull-normal groups, (3) it must be capable of being performed with the usual, simple equipment available, and (4) its performance must be practicable within a 30-minute lesson period (in Swift, 1969, p. 156).

Curtis Digests, Volume VI (Lawlor, 1970). This volume contained studies, completed during 1953-1957, fitting into one of three categories: experimental, analytic, or synthetic. All studies not fitting in one of these three categories were eliminated from this review. Five studies related to the laboratory are cited. Three were completed by the same investigator (Kruglak) who was much interested in laboratory performance in physics. Kruglak investigated methods for construction, administration, and analysis of paper-pencil tests designed to evaluate laboratory instruction in general college physics. He concluded that ". . .In general, all of these commonly used measures of scholastic aptitude are unreliable or very poor predictors of performance test scores" (in Lawlor, 1970, p. 20).

Kruglak also explored the extent to which the ability to solve a laboratory problem on paper related to the ability to solve the same problem with apparatus and materials. He compared essay and multiple choice forms of a paper and pencil test with a performance test. Kruglak worked with 83 premedical students and 82 engineering students, all of whom had completed two quarters of college physics. One group took the performance test and the essay test; the other, the performance test and the multiple choice test. Students were given familiar laboratory problems, originally unfamiliar problems, and a group of specific skills and techniques with the order of the test and problem presentation randomized.

Kruglak failed to find any significant correlations among the three types of tests. The difference between the mean of the multiple choice test and the means of the other two tests was significant but there were no significant differences between essay and performance tests means. Certain practice effects were found--the essay or the multiple choice test produced greater differences in means of the performance test than the reverse, with the effect of the multiple choice test being more pronounced than the essay. Familiar problems were easiest on the performance test and most difficult on the essay. Skills and techniques tested equally well on all

three forms. Except for skills and techniques, the paper and pencil tests were, at best, only crude approximations of students' ability to deal with laboratory materials and apparatus in the solution of problems. The multiple choice test was probably the least suitable type of test for evaluating originality, Kruglak reported (in Lawlor, 1970, p. 21).

The third study by Kruglak during this period was not reported in the main section of the Digest because statistical data were not reported in the article analyzed for the review. This study involved the determination of the effects of high school physics, sex differences, and the college laboratory on the scores of four laboratory paper-pencil tests in college physics.

Lahti investigated the effectiveness of the laboratory in developing students' ability to use the scientific method and found no significant differences among the four methods studied (inductive-deductive, historical, theme, and standard).

Rosen's study (1954) involved tracing the development of the American high school physics laboratory from its beginning in the early 1800's to its domination of science teaching in 1910. (This information has been discussed in an earlier portion of this paper.)

USOE Reviews of Research. The review covering 1951 (Johnson, 1952) contains the citation of Kruglak's study on individual laboratory vs. demonstration methods of teaching elementary college physics. An additional study cited is one by Diamond who was interested in seeing if students gained anything from their experiences in chemistry laboratories: information, laboratory techniques, development of logical or scientific thinking, or the understanding of science. Diamond's sources of data were reference books, periodicals, and control groups, according to the USOE review. Diamond reported little difference between laboratory and demonstration methods relative to the learning and retention of chemistry facts. He said 10 other investigators had found the demonstration method to be superior but 11 had found in favor of the laboratory. Three, in addition to Diamond, found no significant differences. Diamond concluded that the findings appeared to indicate that the laboratory method was better for developing resourcefulness, techniques and manipulative ability. The demonstration method was better for immediate recall and the ability to think logically.

The 1952 USOE review (Johnson, 1953) contained a citation to a study by Kruglak in which he looked at the achievement of physics students with and without laboratory work. Three groups of 38 students each were involved, one with individual laboratory activities, one with demonstrations, and one without either the laboratory or demonstrations. All attended the same lectures and took the same tests. Test scores of the students having laboratory experience were superior to those of the other two groups although the laboratory experience did not significantly influence their scores on paper-pencil tests.

In the 1953 USOE review (Brown, Blackwood, & Johnson, 1955) a study by Lucow was described in which he investigated the use of the textbook vs.

the laboratory for teaching introductory high school chemistry to college preparatory and to general education students. Lucow reported that, for college preparatory students, both methods produced a statistically significant increase in variation but the laboratory produced the greater increase.

Review of Educational Research (RER), 1950-1970. In Volume 21, Issue 4, October, 1951, one of the conclusions of a study by Nelson was reported to be ". . .d) the roles of the textbook, laboratory work and field trips in the teaching of physical science have not yet been clarified." (Meder, p. 255) A study by Anderson on achievement in chemistry, which was based on a survey of 17 teachers in 8 states, was described. Anderson found that, in his limited sample, students achieved significantly more in chemistry when they received laboratory work rather than demonstrations and when they had two double periods per week rather than five periods per week for both class and laboratory work. Anderson also surveyed biology teaching and reported that students achieved more in biology when the number of laboratory hours received was in the upper quartile of the state distribution (Burnett & Porowski, pp. 264-265).

Washton's survey of college general education courses in science was also reported in this issue. Of the 84% return to his questionnarie, Washton reported that 46% had science survey courses, most of which ran for two semesters and omitted laboratory instruction. Some institutions used demonstrations in these classes, but many did not.

During this period of time the idea of the laboratory's primary purpose in science appeared to be that of demonstrating facts and phenomena already learned -- to illustrate and show and not to experiment. In a study by Forbes, six criteria for significant laboratory experiences were identified: (1) they should involve a cooperatively planned group project; (2) students should experiment with concrete materials; (3) materials should be observed and manipulated with the understanding of their general position in the environment, with some familiar element(s) for the individual; (4) the procedures to be followed should be determined by the group, with a need to know the reasons for details; (5) the abilities and the backgrounds of the group should be used in doing the experiment; and (6) the focus of attention should be on ideas contributed by the experience to the association of ideas in which the problem or question occurred (Richardson, et al., pp. 286-287).

In Volume 27, Issue 4, October, 1957 (Smith & Washton), there was some identification of studies related to the use of laboratory activities in the elementary school section of the issue but insufficient details were included for analysis. Two of these studies were aimed at the development of criteria for selecting laboratory experiences to be included in courses in science for preservice elementary school teachers.

Lucow's study, described in a USOE review, was included in this RER issue. So was the report of a study by Smith to investigate the use of experiments in general science courses at the junior high school level. A large number of experiments were judged suitable for use with the individual method, with move than half of these being suitable for individual laboratory work.

A study by Miles on the organization and teaching of a high school physical science course was mentioned and used as an indicator that individual laboratory experiences could be made suitable for the development of the understanding of basic principles of the physical sciences.

Volume 31, Issue 3, June, 1961, contained a review of an article by Schwab in which he urged a reorientation to the role of the laboratory. Schwab suggested that the laboratory should be viewed as a place ". . . where nature is seen 'more nearly in the raw' and where 'things seen' are used as occasions for the invention and conduct of programs of inquiry . . ." (Smith & Homman, p. 290). However, a study by Breukelman et al. which involved college biology sections produced ". . . no evidence that students taught by the lecture-only method varied significantly in achievement from those taught by the lecture and laboratory method. . ." (Miles & Van Deventer, p. 305).

A study by Hilton on the evaluation of the laboratory in a physical science course for non-science majors was described. Feedback from students indicated they felt the laboratory was valuable, that it improved their understanding of lecture topics, and that it illustrated experimental problem solving in which answers had to be based on evidence (p. 305-307). In this study there was no evaluation of the contribution of the laboratory to the retention of knowledge of science principles or to the acquisition of scientific attitudes and of problem-solving skills.

The third issue of Volume 34, produced in June, 1964, contained information about science education research completed during the 1960-1963 period. In a discussion about NSF curricula, laboratory acitvities were described as designed to be less illustrative and more investigative and quantitative than they had been. Laboratory work often preceded class discussion and was used to stimulate questions rather than to answer them (Hurd & Rowe, p. 287). Research studies began to be published in which some NSF curriculum project was compared with a more traditional way of teaching. Such studies were criticized on the basis that ". . . valid comparisons of goal achievement cannot be made between two courses that have no common goal. . ." (p. 288).

Two research studies, both resulting in findings of no significant differences, were reported about the use of the laboratory. Oliver used three methods of teaching biology (lecture-demonstration, lecture-discussion-demonstration, and lecture-discussion-demonstration-laboratory work) and measured the effects of these methods on factual information acquired, overall achievement in biology, application of scientific principles, and attitudes toward science and scientists. Grassell looked at filmed instruction vs. lecture-laboratory instruction.

Mattheis used two approaches to laboratory work in college science courses for preservice elementary teachers. The control group was given "recipe" laboratory exercises while the experimental group worked on science projects. The project laboratory was superior to the control laboratory in producing gains in science knowledge for students who pretested high in science knowledge and interest, but the control

laboratory was superior for those students who pretested low in science knowledge and interest (Burnett, 1964).

An article by Michels, originally published in the American Journal of Physics, was discussed because of its identification of the characteristics the modern teaching laboratory should exhibit. According to Michels such a laboratory (1) should lead, whenever possible, to results not known in advance by the student; (2) should lend itself to differing degrees of precision; (3) should demand, whenever possible, some theoretical analysis; (4) should involve apparatus that is as simple as possible so the student can understand the operation of the devices that he uses; and (5) at some stage of work, the laboratory situation should force the student to make a choice of procedures on the basis of the work already completed (Van Deventer, p. 335).

An interesting section in this issue contained some criticisms of research on teaching methods, as discussed by Travers. He suggested that there was a need to start with a theory of learning in the classroom which would postulate specific changes in conditions of learning that would lead to changes in performance. Also, research tended to deal directly with phenomena rather than a selection that would (a) provide special opportunities for throwing light on some broad problems of education or (b) allow generalizations to be made about the value of particular practices for achieving specified goals (p. 379).

Volume 39, Issue 4, October, 1969, contained an analysis of the science education literature for the period of Fall 1964-Winter 1969. The focus of this issue was topics of current significance in science and mathematics education. There was more consideration of broad questions and less reporting of specific studies as had been done in past issues. Laboratory work was mentioned, in a chapter by Robinson on the philosophical and historical bases of science teaching in reference to its use in the NSF science course improvement projects, as the major device for teaching processes.

Science Education Reviews. Annual and topical reviews of research, produced primarily by persons associated with the U. S. Office of Education, were published in the journal Science Education in the 1950's and early 1960's. These reviews were coordinated by members of the National Association for Research in Science Teaching (NARST). Reviews identified were as follows in volume 38(1), February, 1954, by Anderson (pp. 6-38), by Mallinson and Buck (pp. 58-81), and by Buck and Mallinson (pp. 81-101); in volume 38(5), December, 1954, by Anderson, et al., (pp. 333-365); in volume 39(2), March, 1955, by Brown, Blackwood, and Johnson (pp. 141-156); in volume 39(5), December, 1955, by Smith, et al., (pp. 335-356), by Fraser et al., April, 1956, (pp. 357-371), and by Blackwood and Brown (pp. 372-389); in 40(3) by Mallinson (pp. 206-208); in 40(5) December, 1956, by Boeck, et al., (pp. 337-357), and by Fraser et al., (pp. 363-387); in volume 41(5), December, 1957, by Obourn, et al., (pp. 375-411); in volume 44(5), December, 1960, by Obourn and Boeck (pp. 374-399); and in volume 46(2), March, 1962, Wheeler et al., (pp. 133-139).

Nine studies related to the laboratory were found in these Science Education materials. Several of these studies (Kruglak, Lucow) have been

discussed earlier in this paper. Three studies contained findings in support of the use of the laboratory: significant gains in science attitudes were found only for the group using the individual laboratory method in general education physics in Balcziak's study [39(2):143-144, April 1955]. Lucow reported [39(2):149, April 1955] that the use of the laboratory approach in high school chemistry classes produced statistically significant increases in variation for the non-accelerated, non-college preparatory students. Lathi [41(5):394, December 1957] found the inductive-deduction or problem-solving use of the laboratory in a natural science class for non-majors was significantly superior in promoting the ability to develop a line of attack for problem solving.

The authors (Obourn, et al, 1957) of the fifth annual review, in discussing the research surveyed for this review, wrote

> The effective use of the laboratory in college science has been an almost perennial problem reflected in the research literature. . .When one considers that perhaps the most unique thing about learning in science is the experiment, it is surprising to see that no studies are currently reported which deal with the experimental exercise as a learning situation in elementary science.
>
> At the junior high school level the individual experiment has almost disappeared in favor of the pupil and/or teacher-demonstration . . . It is hoped that children in the elementary school will have a rich experience in direct learning through experimental exercises. . . (pp. 404-405).

ERIC/SMEAC-NARST Reviews and Related Reviews. Individuals at Michigan State University (Taylor et al., 1966) reviewed the science education research literature which involved the secondary school level for the years 1963-1965. They identified 195 titles, located 125 abstracts or articles, and discussed 57 studies in the body of the review. One of these, by Coulter (1966), involved a comparison of the inductive laboratory-inductive demonstration method and the deductive laboratory. Another group of science educators at The University of Texas (Lee et al., 1965) reviewed science education research at the college level for July 1963-July 1964. (Thirty-eight of the 59 studies identified were doctoral dissertations.) Twenty-four of the studies were selected for abstracting. Programmed instruction was a popular topic of investigation. Schefler looked at the discovery laboratory vs. the traditional laboratory and White investigated the biology knowledge of students who had no hours of laboratory, as compared to four hours, per week. Most research was done with students in freshman-level college science courses.

The ERIC Clearinghouse for Science, Mathematics and Environmental Education (ERIC/SMEAC) in cooperation with the National Association for Research in Science Teaching (NARST) took over the responsibilities of the annual review of research in science education, beginning with the years 1965-1967, although a review of research on elementary school science for 1963-64 was completed to tie in with the efforts of the Michigan State and Texas groups. This cooperative effort still continues, with the most recent review for 1979 being in press at the time this paper is written.

The reviews for the years 1965-1969 are by educational levels, but beginning with the 1970 review all three levels have been combined into one review. Authors for these reviews are chosen by the two groups involved (ERIC/SMEAC and NARST). These individuals are free to involve colleagues in the production of the review and also may decide upon the approach they take in reviewing the literature. Although this allows for variation in the style of a particular review, methods of instruction, or instructional techniques and procedures, or some similarly titled section is usually identifiable in each review. It is in these sections that research related to the use of the laboratory is most often located.

There were no additional studies related to the science laboratory in the research for 1963-64 when the elementary level review was included. Cunningham and Butts (1970) commented that, in their opinion, ". . .to determine the adequacy of the effectiveness of an instructional procedure, the research design should include a treatment group and a comparison group with evidence of pre- and post-test gain . . ." (p. 1) but only one study they reviewed did so.

The reviews for 1965-1967 showed no studies identified with the use of the laboratory by elementary pupils, three studies at the secondary level that involved comparing the laboratory with other methods of instruction (of 17 studies identified related to instructional procedures and classroom organization), and eight studies at the college level which involved the use of the laboratory as compared with some other method. Westmeyer et al. (1969), in commenting on the "instructional procedures" studies at the secondary level, wrote that there appeared to be interest in teaching inquiry in the laboratory via open-ended investigations but ". . . there is not yet a firm basis of concrete evidence supporting the effectiveness of this practice. . ." (p. 10).

Montean and Butzow (1970), in discussing the instruction research at the college level, said

> . . .It has been shown by most of these studies, that laboratory work is not particularly helpful in achieving the course objectives of traditional courses as measured by the instruments used. If laboratory work is considered in more depth, particularly if the kind of thinking which laboratory work is designed to produce is analyzed, then there is some evidence for the choice of an inductive approach over an approach in the laboratory designed for illustration or validation of principles presented in the lecture. . . . (pp. 4-5).

The research reviewed for the years 1968-1969 shows the influence of the NSF science curriculum improvement projects. Studies in the instruction section of the elementary level review were grouped under the headings of project acronyms: SAPA, SCIS, ESS. Four studies are cited that provide evidence that children can generally achieve objectives of instruction if objectives and educational experiences are consistent with each other. Forty-eight studies were identified in the "instructional procedures" section of the secondary level review although these really were 43 in

number when duplicates were removed. Areas of research included open-ended vs. directed laboratories, expository-deductive vs. discovery-inductive laboratories, and variation in the format of laboratory reports. In discussing one study involving a comparison of the use of the laboratory with other instructional methods, the author of this review introduced it with the comment ". . . in what should probably be the last study of this type, . . ." (Welch, 1971, p. 38).

The college level review for 1968-1969 (Koran, 1972) reported studies as either descriptive or experimental research. In the experimental research section, two studies were reported which involved the comparison of methods of laboratory instruction. Chanin looked at scheduling patterns--three one-hour laboratory periods per week as compared with two one-and one-half hour labs per week and found the shorter periods significantly better than the longer ones. Richardson reported on the use of an inquiry-discovery laboratory method with a control group. In all, ten studies were cited that related in some way to the use of the laboratory.

The authors of the 1970 review commented that "tight definitions" of inquiry teaching were absent in the research (Trowbridge et al., 1972, p. 30). Studies relating to the use of the laboratory were found in the "methods of instruction" section as well as in the section entitled "laboratory practices." The reviewers concluded that, because of the small number of studies identified, science educators were ". . . satisfied with the present laboratory setup. . ." (p. 45). Seven studies were found in the college section, grouped as comparative studies: laboratory programs.

No studies involving the use of the laboratory were found in the elementary section of the 1971 review. In the secondary education section, a study by Egelston was cited as being a good example with much descriptive detail. In the college section, the author devoted considerable discussion to the weaknesses of comparative research (Anderson, 1973, p. 16).

Research completed in 1972 was viewed from the paradigm of Ausubel's learning theory. A subsection in the instruction section did contain some reference to laboratory activities but most studies in this section involved the use of media and/or materials as the problem to be investigated. The author did cite an article by Hurd to the effect that science education is in need of a theory base for instruction and that, because we operate on a theoretical basis, instructional fads go unchallenged (Novak, 1973, p. 18-19).

The authors of the 1973 review emphasize Novak's contention, expressed in the 1972 review, that - since 1920 - most investigations which focused on the impact of different instructional regimes resulted in no significant differences (Novak, 1973, p. 8) and say that such was generally the case in the research published in 1973. They are not certain, however, that they agree with Novak's desire for more steeping in learning theory (Rowe and DeTure, 1974, p. 5).

Herron et al (1974), in discussing research published in 1974, discussed the fact that an instructional system is complex and that most of the variables extant in the system have been shown to affect learning under

some set of conditions: teacher and student personalities, difficulty of the learning material(s), method of instruction, reading level of the materials, and kind and amount of laboratory activity. In the "implications" section of this review they re-emphasized the idea that we do not know the set of conditions under which each of the variables studied will or will not have an influence. For example, the expository method probably is better when the material taught is so difficult that students are unlikely to discover important relationships on their own. They emphasize that thinking discovery learning is always good or bad is "simplistic."

The 1975 review, by Mallinson (1976), does not contain any citations of laboratory studies until the college level is considered. Three studies are discussed. King, using an audio-tutorial biology laboratory vs. a traditional biology laboratory, found a significant improvement in attitude toward biology in the experimental group. Wheatley's study of a college general biology course showed that the experimental group scored significantly higher on the items involving the higher levels of Bloom's taxonomy of the cognitive domain when they had completed more than one-half of the special laboratory activities available to them. Rowsey and Mason studied the use of the conventional lecture-laboratory setup as compared to an audio-tutorial approach and found results significantly in favor of the audio-tutorial group.

The authors of the 1976 review discussed problems inherent in studying teaching methodology, some of which are beyond the control of the researcher. It is difficult, if not impossible, to apply research results in a setting different from that of the original researcher relative to student achievement with respect to content. There is great variability in the meaning of "achievement" and this variability reflects the lack of a common theory base for the practice of and research in the profession of science education. The authors call for the beginnings of the establishment of one or more theory bases for science education (Renner et al., 1977, p. 34).

The 1977 research review looked at studies clustered on the basis of the research design involved: ex post facto, survey, or experimental. No studies on the use of the laboratory were discussed. This lack, combined with the 1976 review in which no studies on the role of the laboratory per se were discussed, may indicate that science education researchers are beginning to heed Welch's (1971) plea for the abandonment of comparative studies involving the use of the laboratory. However, it may only indicate that the author's biases in reporting and discussing research were such that laboratory studies did not merit discussion.

But, the laboratory reappeared in research published in 1978 (Gabel, et al., 1980). The studies cited under "laboratory approaches" in the 1978 review were a mixed lot. Tamir reported on the actual use of high school and college laboratories. Webber studied the effects on delayed retention and consequent transfer in physics and found no significant differences. David looked at the use of lecture-discussion, inductive laboratory, and verification laboratory activities with fifth and sixth grade students and found no significant differences in achievement but found the inductive

laboratory more effective in producing positive attitudes toward science and a better understanding of science. Spear reported on the use of the lecture-laboratory vs. lecture-only in college geology and found the lecture-laboratory group had 10% higher achievement scores. Lee attempted to identify the role of laboratory instruction in biology and reported that five major functions were identified and affirmed.

Gabel et al., concluded that these studies showed that the laboratory was not particularly effective in increasing students' knowledge of subject matter but that it did increase attitudes (p. 459).

Butts, in the 1979 review (in press), reported some investigations focused on the use of hands-on activities vs. textbook instruction in elementary school science. Story and Brown found a significant change in student attitude with hands-on instruction, but Cohen reported no significant differences in a study designed to change cognitive development. Some research involving the use of the laboratory in secondary school science was reported, but the majority of the studies involved college students. Butts concluded that, with college students, expository and hands-on strategies are both effective.

When science education research published during the last 15 years and summarized in various reviews is considered, it is evident that Novak's (1973) characterization of research on the study of instruction as a "classic" area continues to be true. Although the emphasis may vary from that of the laboratory vs. some other method to the use of NSF science curriculum materials vs. conventional programs and materials, researchers are still concerned with finding the most effective means of instruction.

Combined with the desire to find the most effective means of instruction is the long-held belief that the laboratory is an important means of instruction in science. Further consideration of currrent research on the role of the laboratory is found in a later section of this paper. It seems logical next to take a look at opinion statements about the role of the laboratory in science teaching as these have been made by the science education community over the years, even when -- or, especially when --, these opinion statements are not directly supported by research evidence.

THE ROLE OF THE LABORATORY IN SCIENCE TEACHING: OPINION STATEMENTS

It is possible to find in the literature discussions of the science laboratory that do not have a research base. Frequently these materials have as their focus a listing of the objectives for science teaching, with the identification of the role(s) the laboratory can play in their achievement. Less frequently one may find an article in which the author considers whether or not the laboratory should be retained. Usually such article ends with the conclusion that the laboratory should be retained but that its present form needs to be modified in order to make it more effective or more in keeping with the current trends in science education. Even less common are articles whose authors suggest that laboratory courses are a waste of time (Pickering, 1980).

In Favor of the Laboratory

Persons advocating the use of the laboratory as an instructional method in science frequently support their position, not with research data, but with the idea that the laboratory will aid in the achievement of educational goals considered desirable: scientific literacy, knowledge of the scientific enterprise, and other worthy aims. Sometimes they suggest that the times "call for" the use of the laboratory (Schwab's milieu factor).

The authors of the 59th NSSE Yearbook (Henry, 1960) wrote,

> Changing conceptions of the values and purposes of science teaching have tended toward an increasing emphasis upon laboratory work. The nature of the scientific enterprise is found in the methods by which problems are attacked. Therefore, more attention should be directed to the processes or methods of seeking answers in the laboratory rather than putting so much stress on finding exact answers. More time should be spent by students in developing insights as to how data may be processed and predictions made from them. (p. 334)

Hurd (1964), writing in Theory Into Action, produced by the National Science Teachers Association's Curriculum Committee, said the goal of science teaching is to develop scientifically literate citizens. According to Hurd

> Laboratory and field work are central to the teaching of science. Learning from work in the laboratory and field is central to the teaching of science. It is here that the student relates concepts, theories, experiments, and observations as a means of exploring ideas. While technical skill and precision are important outcomes of the laboratory, it is the meaning they have for the interpretation of data that is more important.(pp. 13-14)

Students need to explore ideas, test theories, raise questions. They need to go beyond collecting data -- they need to formulate statements based on data and test these statements against theory. ". . . The conclusion of an experiment is found in the interpretation of data, and it is this interpretation that generates new questions, stimulates further inquiry, helps to solve problems, and leads to the refinement of theories." (p. 14) Apparently, these activities would help students develop into scientifically literate citizens.

A knowledge of how a scientist goes about his/her work appears to be an objective closely related to that of scientific literacy. Experiencing the methods scientists use, via laboratory activities, may lead to a more scientifically literate citizen. It may also lead to continued interest in science as a career.

Another reason given for using the laboratory is that it is necessary if students are to learn scientific content. (Many research studies are devoted to testing for achievement.) Some remarks of Bentley Glass (1959) are relevant to this position. These comments are found in the minutes of the American Institute of Biological Sciences, Biological Sciences Curriculum Study meeting of the Committee on Innovation in Laboratory Instruction. Glass suggested that the group needed to examine the true function of laboratory work for students and to consider why laboratory work was initiated.

Glass said,

> . . .Is laboratory work in honest fact necessary for a student to obtain a good grasp of biological concepts and principles and the observations on which they are based? . . . There seem to be two conceivable functions of laboratory work . . . The first function of laboratory work was probably the principal one in the minds of Thomas Henry Huxley and Louis Aggasiz when they introduced it in biology. . . Their truth was a simple one: seeing is believing. . .one looks squarely at the facts, the infinitely varied phenomena of nature. Thus, the first function of laboratory work was to present the evidence, to illustrate from nature the basis of our biological concepts.
>
> The second function of work in the laboratory is to convey something to the learner of the nature of science, of its method and the spirit that pervades it. . . . in the scientific laboratory the novice learns for himself how to ask questions of nature and how to obtain unequivocal answers (even though couched in terms of probabilities rather than certainties). . . (pp. 3-4)

Glass (1959) goes on to say that audiovisual aids, demonstrations, the open laboratory, and photography may suffice to fulfill the descriptive function of the laboratory but ". . . For the other function something entirely different is needed and at the present time we have no certain knowledge of how long a period of work is needed to achieve this aim. . ." (p. 4)

He also suggests that it is not necessary to have laboratories parallel all lectures and class discussion topics. Glass (1959, pp. 4-5) makes the point that all scientists do not possess all skills, nor do they know all techniques or how to operate all types of scientific instruments. Thus, the idea of laboratory blocks in biology concentrating on certain topics was given support. It is interesting to see that the support for this curriculum innovation was based not on research data but on personal opinion about what the science laboratory should be, or do.

Baillie, (no date), in a publication written for the Nebraska State Department of Education, proposes that laboratory work should be used with disadvantaged youth in the middle school. His main reason for proposing laboratory work for this age and type of pupil is that such students can very easily lose interest in school and school work. Being involved in laboratory activities should stimulate interest in science and, it is hoped, interest in completing high school. The use of discovery activities capitalizes on the middle school child's natural curiosity about the world. Baillie wrote, "The laboratory approach is crucial throughout the school year, and its general nature should change from illustrative in the early grades, to investigative in the later grades. . ." (p. 6). The use of laboratory work makes the pupil active rather than passive in the learning process.

Individuals involved in the development of the Human Sciences program also cite the need for student involvement in learning. They stated (1973, p. 43) that Piaget advocated that children should be able to do their own experimenting and their own research. The essential element is that, in order for a child to understand something, he/she must construct it for himself/herself, he/she must re-invent it. Children need to be allowed to discover for themselves rather than being taught something.

The Human Sciences writers criticize existing curricula, saying

> . . .Most curricula for sixth, seventh, and eighth grade students presuppose they are capable of principled logical and moral thought. We find this presupposition inconsistent with knowledge of human development, agreeing with Kohlberg that new curricula must be formulated as tools for developing such thought processes. Most science curricula are organized in logical subject matter topics that reflect a choice of selected elements of a discipline. Materials are designed to motivate and interest the student in understanding the subject matter. In a sense, the student's concerns and development are subsurvient to the subject matter organization . . . When the materials fail to motivate or interest the student or when he fails to learn, the responsiblities for failure are variously assigned to teachers, to students, and to parents. We suggest that the theoretical base of traditional education produces failures as a consequence of its assumptions. No amount of reform can eliminate student failure within this paradigm. (p. 51)

And they identify the following teaching and learning strategies to use with middle school children: observing, questioning, describing, speculating, interpreting, valuing, choosing, verifying, and experimenting.

Outcomes and Objectives of Laboratory Work

Other authors talk in more specific terms of outcomes of laboratory work or of specific objectives to be attained through the use of laboratory experiences.

Shulman and Tamir (1973, p. 1119), in their chapter in the Second Handbook of Research On Teaching, grouped objectives sought through the use of the laboratory into five categories: (1) skills--manipulative, inquiry, investigative, organizational, communicative; (2) concepts--for example, hypothesis, theoretical model, taxonomic category; (3) cognitive abilities --critical thinking, problem solving, application, analysis, synthesis, evaluation, decision making, creativity; (4) understanding the nature of science--scientific enterprise, scientists and how they work, existence of multiplicity of scientific methods, interrelationships between science and technology and among the various disciplines of science; and (5) attitudes --for example, curiosity, interest, risk taking, objectivity, precision, confidence, perseverence, satisfaction, responsibility, consensus, collaboration, and liking science.

Pella published an article in The Science Teacher (1961) in which he reported that he had analyzed high school science textbooks and laboratory workbooks and had also interviewed 140 teachers to identify the objectives or functions of laboratory activities. Pella listed eight functions:

1) a means of securing information,
2) a means of determining cause and effect relationships,
3) a means of verifying certain factors of phenomena,
4) a means of applying what is known,
5) a means of developing skill,
6) a means of providing drill,
7) a means of helping pupils learn to use scientific methods of solving problems, and
8) a means of carrying on individual research.

He also reported that he had reviewed courses of study or curriculum outlines from 22 states or individual school systems for their objectives for teaching science and found seven that appeared in these materials.

According to Pella, these commonly-held objectives were:

1) understanding science course content,
2) learning methods of science,
3) developing scientific attitudes,
4) developing desirable social attitudes,
5) stimulating interest in science,
6) learning how to apply the principles of science, and
7) developing an appreciation for the growth and development of scientific knowledge.

Pella concluded that, while these two sets of objectives appeared to be related, the presence or absence of the laboratory did not influence the realization of these goals. The laboratory can be used as a dispenser of knowledge, serving for drill or verification, or as a place where knowledge is discovered.

The teacher determines which function the laboratory fulfills in instruction. To illustrate this, Pella developed a table in which he described five different instructional situations (1961, p. 31).

Degrees of Freedom Available to the Teacher Using the Laboratory

Steps in Procedure	I	II	III	IV	V
1. Statement of Problem	T	T	T	T	P
2. Hypothesis	T	T	T	P	P
3. Working Plan	T	T	P	P	P
4. Performance	P	P	P	P	P
5. Data Gathering	P	P	P	P	P
6. Conclusion	T	P	P	P	P

T - Teacher P - Pupil

If a teacher's primary objective for using the laboratory is skill development, situations I or II would apply; if the methods of science are to be stressed, then situations IV or V should be used. A teacher concentrating on promoting individual pupil research would use situation V.

If the teacher believes that the function of science class is to transmit the factual heritage of a civilization, then the laboratory's primary use is a deductive one and laboratory work comes after the teacher has lectured or the pupils have read the textbook. The laboratory then serves for verification. If teaching is inductive and pupils are to discover, laboratory activities come before any teacher lecture or reading about a science topic or problem (Pella, 1961, 29-31).

An earlier publication about science education (NASSP Bulletin, 1953, pp. 102-103), written to be read by public school administrators, contained the following listing of functions that the laboratory can serve as well as or better than any other learning activity:

1) skill development in critical thinking, problem solving;
2) learning to observe rather than to look or see;
3) the development of initiative, resourcefulness, cooperation;
4) insight into the work of a scientist and the role of the laboratory in mankind's progress;
5) improved understanding of basic concepts, principles, and facts of science (by providing contact with actual equipment and processes of science);
6) increased proficiency in generally useful skills: recording, organizing and analyzing information, making readings on measuring instruments, handling equipment;
7) development of interest in and curiosity about science principles and processes -- as an avenue to future science learning.

The author does admit that these are not automatic or guaranteed outcomes of laboratory work.

Another publication from the 1950's was the report of a conference focused on the theme "Educating a Chemist" (Andrews, 1957). In chapter three of the conference report, the discussion was about pre-college science--what should the content be (facts vs. principles?). Conference participants felt that very little of what was taught in high school was retained in college. (See a study by Brown in the "more recent research" section of this paper for another look at this problem.) Therefore, conference participants reasoned that if students could acquire the ability to solve problems in high school, perhaps this ability would remain with them when they enrolled in college. And, if they had to use facts in solving problems, perhaps the facts would stick longer.

Conference participants considered the role the laboratory should play.

> . . .Our Conference had a strong conviction of the importance of having laboratory periods in pre-college chemistry and that lecture demonstrations are no substitutes. Moreover, to make the laboratory meaningful, it must have sufficient equipment and facilities for meaningful experiments. A double-period for laboratory, an hour and a half to two hours instead of chopped up single periods, can be an essential factor in making the laboratory meaningful.
>
> What should the objectives of the laboratory be? The problem is very much like that of the objectives of the classsroom. The acquisition of specific skills, the learning of specific processes may not be too permanent; the improvement of general skills may in the long run be more important. In the middle teens the power of observation of the unfamiliar should be ready to be developed. Accurate note-taking and accurate computation should be within the grasp of the student and will be a most valuable asset for future years. Even the ability to push forward a little bit into the unknown and to try to make sense of it, should be ready for development.
>
> If there is to be a real incentive to produce this investigative ability, the experiment in the laboratory at this level must be challenging . . . (p. 20)

By the mid-to-late 1960's the science course improvement projects were in use, even if on a limited basis, and the emphasis on enquiry (or inquiry) was appearing in the literature. Some opinion statements reflected these influences. For example, Sund and Trowbridge produced a science methods textbook entitled Teaching Science by Inquiry (1967). In it they wrote about skill development in the laboratory and classified skills as (a) acquisitive, (b) organizational, (c) creative, (d) manipulative, and (e) communicative. Each of these categories was further subdivided into more specific skills.

Acquisitive skills included (1) listening, (2) observing, (3) searching for sources and acquiring library skills, (4) inquiring, (5) investigating, (6) gathering data, and (7) research. Organizational skills

involved (1) recording, (2) comparing, (3) contrasting, (4) classifying, (5) organizing, (6) outlining, and (7) reviewing. Creative skills were (1) planning ahead; (2) designing a new problem, approach, device or system; (3) inventing; and (4) synthesizing. Manipulative skills were (1) using an instrument, (2) caring for an instrument, (3) demonstration, (4) experimentation, (5) repair, (6) construction, and (7) calibration. Communicative skills consisted of (1) asking questions, (3) discussion, (3) explanation, (4) reporting, (5) writing, (6) criticism, (7) graphing, and (8) teaching to classmates (pp. 93-95).

Sund and Trowbridge advocated that junior high school students be involved in laboratory activities. They listed 15 knowledges and skills that laboratory work could help junior high school students develop:

1) understand the purposes of the laboratory in the study of science,
2) understand and become familiar with the simple tools of the laboratory,
3) understand and use the metric system in simple measurement and computation,
4) attain the understanding necessary for the proper reporting of observations of an experiment,
5) keep neat and accurate records of laboratory experiments,
6) understand the operation of simple ratios and proportions,
7) understand the construction and reading of simple graphs,
8) understand and use the simpler forms of exponential notation,
9) understand the proper use and operation of the Bunsen burner,
10) use the slide rule for simple operations,
11) understand and demonstrate the use of a trip balance,
12) ability to work with glass tubing in performing laboratory experiments,
13) keeping glassware and equipment clean,
14) putting together simple equipment in performing laboratory experiments, and
15) measuring accurately in linear, cubic, and weight units. (pp. 102-103)

Sund and Trowbridge also identified nine "safety skills" that laboratory work could develop in students:

1) ability to handle glass tubing,
2) ability to heat test tubes of chemicals,
3) ability to handle acids,
4) ability to test for the presence of noxious gases safely,
5) ability to treat acid spillage or burns from caustic solutions,
6) ability to operate fire extinguishers,
7) ability to set up gas generators properly,
8) ability to use standard carpenter tools, and
9) ability to use dissecting equipment. (p. 106)

They listed, but did not elaborate on actual methods involved, 20 specific student laboratory activities that may be evaluated (p. 104); and, they identified eight goals for laboratory work:

1) to develop skills in problem solving through the identification of problems, collection and interpretation of data, and drawing conclusions;
2) to develop skills in manipulation of laboratory apparatus;
3) to establish systematic habits of record keeping;
4) to develop scientific attitudes;
5) to learn scientific methods in the solution of problems;
6) to develop self-reliance and dependability;
7) to discover unexplored avenues of interest and investigation; and
8) to promote enthusiasm for the subject of science. (pp.103-104)

A different set of objectives students could develop through laboratory work was also published in 1967 by Jeffrey as an article in Science Education based on his doctoral work. He stated that success in the laboratory depends on something other than the ability to manipulate symbols and that measurable outcomes to be achieved as a result of laboratory experiences should be decided upon before the course begins so the course syllabus can be organized correctly. Jeffrey proposed six student performance objectives resulting from individual laboratory work. These consist of (1) vocabulary competence --the ability to translate symbols into non-symbols quickly or vice versa (pictures into words or words into objects); (2) observational competence -- recognition of laboratory occurrences, distinguish like from unlike; (3) investigative competence, referring to (a) knowledge of capabilities of laboratory equipment, (b) ability to design experiments to quantify characteristics, (c) ability to design experiments to separate substances, (f) ability to formulate hypotheses, (h) ability to predict effects of actions, (i) ability to search the literature, and (j) ability to use standard handbooks; (4) reporting competence --record laboratory investigations and report the results; (5) manipulative competence -- handle laboratory equipment and supplies rapidly and safely; and (6) laboratory discipline -- self discipline, keeping an orderly laboratory, and exactness in reporting. (p. 187)

Jeffrey provided examples of ways in which these various competences could be tested but admitted that laboratory discipline was harder to test for than were the other five.

The student population with whom Jeffrey was concerned were college students enrolled in chemistry classes. Another author also concerned with college science wrote about the role of the laboratory in the general education of non-science majors. Bradley (1968) emphasized the fact that beginning college science courses play two roles: a first course for majors and a general education/culture course for non-majors. These roles are not always compatible, Bradley said, and perhaps two separate courses are needed. Science courses for non-majors should, or could, have several aims: information, the development of an interest in science, understanding of relationships of science to the environment and everyday life, understanding of the relationships of the sciences, and culture. Bradley highlighted several functions of laboratory work in general education science courses: (1) development of manipulative skill, (2) to aid memory, (3) to give the students the scientific manner of thought and training in drawing conclusions, (4) to provide opportunities for developing the sense

of perception and the acquisition of concepts, and (5) to develop powers of observation. (Bradley had culled these functions from a list of 43 functions of the laboratory developed by Archer Hurd in 1929.) He then asked 47 secondary school science teachers if these functions could be developed without the laboratory. Thirty-three teachers said "No," 12 said "Maybe," and 2 had no opinion.

Bingman (1969), writing about the Inquiry Role Approach to teaching high school biology, identified three skills needed for this activity: (1) asking initial questions, (2) making observations, and (3) organizing observations. He listed six factors common to all modes of inquiry: (1) formulating a problem, (2) formulating hypotheses, (3) designing a study, (4) executing a plan of investigation, (5) interpreting the data or findings, and (6) synthesizing knowledge gained from the investigation. Bingman also listed 12 affective or atitudinal qualities of inquiry behaviors: (1) curiosity, (2) openness, (3) reality orientation, (4) risk-taking, (5) objectivity, (6) precision, (7) confidence, (8) perseverence, (9) satisfaction, (10) respect for theoretical structures, (11) responsibility, and (12) consensus and collaboration.

Hincksman published an article (1973) in which he asked several questions and then stated some conclusions related to the function of the school laboratory. Hincksman asked: What is effective science learning? What are the contributions of Piaget, Bruner, and other learning theorists to evaluating and understanding the function of the school laboratory? What do present day educators consider to be the role of the school laboratory? He concluded, without ever explicitly stating the bases for his conclusions, that (1) the school laboratory is essential for teaching students at the concrete operations stage; (2) laboratory demonstrations or experiments are useful when teaching a difficult concept by reducing it from symbolic to iconic or even the enactive mode; (3) individual laboratory experiences are necessary if the aim is to acquire skill in handling scientific apparatus; (4) in the senior years of pre-college education, when cognitive stages are fully developed, the laboratory may be largely irrelevant except for the manipulative function; and (5) the school laboratory may be used in ways incidential to science teaching -- to promote social adjustment, to illustrate the learning conditions of scientific work, and for motivation (pp. 85-86).

Tamir (1976) claimed there are four major rationales for using the laboratory in science teaching: (1) science involves highly complex and abstract subject matter which elementary students and some high school pupils fail to grasp without concrete objects and opportunities for manipulation, (2) laboratory work gives students an appreciation of the methods and spirit of science, (3) practical experiences promote the development of skills with a wide range of generalizable effects, and (4) students enjoy activities and practical work and consequently become motivated and interested in science (pp. 8-9).

Tamir classified the objectives of the laboratory into (1) skills, (2) concepts, (3) cognitive abilities, (4) understanding the nature of science, and (5) attitudes (pp. 9-10).

Lancaster, in his presidential address reported in Engineering Education (1978), stated that laboratories were needed in engineering education to (1) obtain basic information, (2) provide students practice in how to get data (choose objectives, devise methods, make measurements, record data, check results, decide if more data are needed), (3) acquaint student with the real world, and (4) develop the habit of critical thinking. Citing Piaget, Lancaster said that knowledge begins with the assimilation of data from the environment. Understanding of a concept occurs when an individual thoroughly explores and interacts with the material and discipline of the concept. The learner needs to probe, disassemble, construct, and interact with material, to carry out experiments with freedom of initiative. The student needs to enjoy what he is doing and to be rewarded for success. Teachers need to be interested in and enthusiastic about their subject and to also be interested in students.

White (1979), writing about the relevance of practical work to comprehension of physics, in a British journal, says

> . . . Rather there seems to be a settled faith in the value of practical work, a near religion to which we are prepared to donate large amounts of time and money . . . . only too often it becomes a matter of ritual, the purpose of which is lost. Then practical work is included in courses because it is expected, not for a particular reason . . . (p. 384)

White is not a critic of practical or laboratory work. In fact he advocates the addition of three types of experiments to physics laboratory courses: (1) unusual experiments which engage emotions through being odd, dramatic, beautiful, or puzzling; (2) experiments intended to establish generalized episodes involving materials and events of common experience, with the purposes of linking school subject matter and daily life and of providing experiences which will be called into play in making subsequent information comprehensible; and (3) true problem-solving exercises which serve to integrate the knowledge of physics.

Reif and St. John (1979) were also concerned with physics classes. They described a prototype college introductory-level physics laboratory course which was developed because most students could not meaningfully summarize the important aspects of an experiment they had just completed. Also, the students questioned whether or not the laboratory was worthwhile since it was not particularly interesting or enjoyable.

Reif and St. John decided the laboratory should (1) teach some general intellectual skills likely to be widely useful to students in their future work, (2) teach skills practicing scientists commonly use but which most students do not possess, and (3) involve skills which can effectively be taught and practiced in a laboratory context.

They identified both basic and higher-level skills. Basic skills include (1) the ability to use operational definitions to relate symbolic concepts to observable quantities (subsuming the ability to estimate or measure important physical quantities at various levels of precision), (2) the ability to estimate the errors of quantities obtained from measurements

(involving habitually applying some qualitative or semiquantitative statistical options), and (3) knowing and applying some generally useful measuring techniques for improving reliability and precision (p. 950).

Higher-level skills include (1) being able to describe and talk about an experiment in a form easily understandable to other people (especially, being able to summarize the most important ideas of the experiment and then to elaborate them to any desirable extent), (2) being able to remember the central ideas of an experiment over a significantly long period of time, and (3) being flexibly able to modify the design or measurement procedures of an experiment when confronted with slightly different conditions or experimental goals (pp. 950-951).

In summary. The situation appears pretty much as White described it -- the science education community does have a "settled faith" in the value of laboratory work. Economic circumstances, critics, and some educational research data interject an element of doubt.

Criticisms of the Laboratory

Criticisms of the use of the laboratory may be grouped into administrative and educational areas. Within the administrative area are the criticisms and concerns that the use of the laboratory involves expenditures of both time and money. Money is needed for both facilities and equipment. Time is needed to make proper use of them. The concerns voiced in the historical perspective portion of this publication continue to be heard into the present day. Providing double periods for science classes so laboratory work can be done involves scheduling problems for administrators and problems in perception of teacher load if teachers in other disciplines do not fully understand the various aspects of laboratory teaching in science.

Another concern that is both administrative and educational relates to the problem that Hurd identified: are we teaching science for the citizen or for the future scientist? Can these two goals be achieved within the same science class? Some of the individuals who have written about general education courses in college science appear to believe they cannot and that two types of science courses need to be offered. Secondary schools usually do not have the resources to offer science courses for those students planning to major in science in college and another set for those who will not go to college or who will not major in science if they do go. As a result, junior high and middle school science courses usually have a science-for-the citizen emphasis while senior high school science, possibly with the exception of biology, becomes more tailored for the college-bound student. However, senior high school science teachers are realistic enough to admit that all of their students are not interested in science careers and that the emphasis in the science class and laboratory becomes that of the curriculum materials being used.

Even the advocates of the science laboratory have been critical of the uses to which the science laboratory has been put. During the NSF science course improvement activity, and even prior to that time, there were

science educators who decried the emphasis on verification in the science laboratory. The science course improvement project materials resulting from the NSF-funded projects and later materials that have been patterned after the NSF materials contain laboratory activities that are designed to be investigative rather than illustrative or verificational in nature.

Is a change in curriculum materials sufficient to bring about a change in instructional practices? Not necessarily. Even the advocates of the laboratory emphasize that the key to success is an enthusiastic, well-prepared teacher. Even prior to the development of the NSF materials, Richardson was quoted by Burnett, in a 1948 issue of the Review of Educational Research, as writing that teachers had a very limited conception of the function of the laboratory in the learning situation.

Another critic of the way the science laboratory was being used is Rasmussen (1970). In an article in Bioscience, Rasmussen criticized both college science teachers and teacher educators. He claimed that high school laboratory work is no better than it is because formal science training (at the college level) is ". . . more often . . . about science rather than in science. . ." (p. 292), with very limited opportunities to really investigate ideas. Laboratory activities, according to Rasmussen, are largely illustrative, non-investigative, and not particularly exciting. Laboratory achievement is usually evaluated separately from the science content of the course. "Operationally, he learns that the function of the laboratory should be certification of statements made by the teacher or by the textbook. . ." (p. 292). In science methods courses, the student does not get exposed to ideas about science. Instead, ". . . Most of all he learns by default, how to be bland and avoid any issues that are concerned with value systems. . . ." (p. 293). When people become in-service teachers, they get handed a textbook plus a set of laboratory activities and their behavior is determined by the structure of the program they are supposed to teach.

Rasmussen said that, in good science teaching, "the textbook supports the laboratory but in most present cases these roles are reversed." He pointed out that the BSCS materials (lab blocks, patterns and processes, interactions of experiments and ideas) are not as successful as one might wish ". . . due in large part to teacher reluctance to change their mode of operation" (p. 293).

Tamir (1976), in a report on the role of the laboratory in science teaching, identified 10 "arguments against excessive use of the laboratory" and cited the sources from which the statements came. Briefly, these 10 criticisms are: (1) laboratory activities have little relevance to daily life or problems in which students are interested, (2) there is lack of knowledge about the effective use of laboratories in science teaching, (3) teachers are not competent to teach science and use the laboratory effectively, (4) overemphasis on laboratory activities may lead to a narrow view of science, (5) much laboratory time is spent on trivial experiments, (6) the kinds of laboratory experiences students have will not result in a respect for science (7) laboratory work in the public schools reflects too much of the style of university laboratory courses, (8) demonstrations are better instructional methods for slow learners, (9) girls are less interested in conducting laboratory activities than are

boys, and (10) students can carry out a laboratory activity without intellectualizing what they are doing (pp. 4-5).

A recent article containing criticisms of the college science laboratory was published in The Chronicle of Higher Education (1980). Much of what Pickering said in this article has been said by other individuals at other times but his is a relatively succinct description of the situation. Pickering said that laboratories are (1) very expensive, (2) not popular with students, and (3) time-consuming for faculty.

Although people appear to agree on the need for laboratories for training scientists, the majority of students in laboratory courses do not have this career goal. Administrators think that college faculty are holding on to an archaic goal: the professional school requirement. Faculty members do not help their cause because they are not clear on what teaching laboratories can/ought to do for their students. The laboratory is often asked to do jobs for which it is unsuited and its real strengths are ignored.

Pickering (1980) identified two misconceptions about the use of the laboratory in college science. Misconception one is that laboratories somehow "illustrate" lecture courses. This function is not possible in a simple, one-afternoon exercise, Pickering said, because "most scientific theory is based on a large number of very sophisticated supporting experiments" (p. 80). When a lecture topic can be illustrated, this probably can be done with a lecture-demonstration or with audio-visual aids.

Misconception two is that laboratories exist to teach "finger skills." Pickering claimed that very few of the techniques students learn in their college science laboratories will be directly usable in the careers they plan. The importance of manipulative skills has been oversold, Pickering argued. Many of the skills students learn in the laboratories are obsolete in science careers -- few biologists do dissections and few chemists do titrations. Such skills are worth teaching only as tools to be mastered for basic scientific inquiry and not as ends in themselves (p. 80).

Pickering distinguished between lecture and laboratory courses by contending that a good laboratory course should be an exercise in doing science while a good lecture course has the objective of learning about science. He viewed good laboratory teaching as being essentially Socratic, involving the posing of carefully defined questions to be asked of nature. The intellectual processes students should use are those of real scientific research so they come to see how difficult it is to obtain totally unambiguous data. Such a laboratory course could easily be defended as fitting into a liberal education, according to Pickering. Unfortunately most laboratory courses do not fit this model.

Pickering stated that laboratory courses do not live up to their potential for several reasons. It is not easy to teach a laboratory course. Much attention to detail is required and there are problems of organization and management. In most college science courses, the teaching associates teach the laboratory sections. Faculty members are not prepared for or

comfortable with the role of managing teaching associates. As a result, teaching associates receive few rewards for good performance and are seldom dismissed for poor performance.

There are other problems. "Too few lab courses offer any sort of confrontation with the unknown. . . .The element of creative surprise is almost completely missing. The results of an experiment should be ambiguous enough so that a student is compelled to think through the bearing of his results on the possible conclusions" (p. 80). Grading contributes to the problem because students put their efforts where the rewards are.

As one reads Pickering's article it becomes obvious that he is arguing not for the abolition of laboratory courses in science but for their improvement.

The criticisms just described have been focused on laboratory courses and the ways in which they are taught. Just as teachers and instructional methods have been criticized, so have the materials involved in science instruction.

Part of an article on the nature of scientific enquiry, by Marshall D. Herron (1971), relates to the analysis of some of the science course improvement project materials to determine if they really involved what their developers advocated relative to scientific enquiry. Herron examined CHEM Study, PSSC, and the Blue Version BSCS biology materials. Chemical Education Materials Study materials emphasize

> the importance of accurate observation, controlled experimentation, and the development of 'models' which allow the observed phenomena to be explained and permit related phenomena to be predicted (p. 196).

> The overriding impression one receives from the CHEM Study materials is that truths or 'facts' about unchanging properties of nature come to us <u>from</u> the phenomena. . .The net result is to deemphasize or ignore Schwab's distinction between fluid and stable enquiry by centering the entire story around various aspects of the 'stable' variety. (p. 197)

Herron examined 41 CHEM Study laboratory exercises for their content and stated purpose. He grouped these 41 exercises into three major categories: (1) exercises through which the student was expected to "discover" certain specified principles or regularities in chemical phenomena; (2) exercises involving inference or problem-solving behavior and having no predetermined, unique solution; and (3) exercises said to "illustrate" or to "give the student the chance to observe, together with exercises intended to give the student practice in developing laboratory techniques."

According to Herron, 24 of the 41 laboratory exercises (more than 50%) were of the illustrative-demonstrative variety. Six were of the open-ended problem-solving type, with four of the six occurring very late in the course. Herron found an identifiable generalization element in only 11 of the exercises (about 25%). He concluded, "In the light of this analysis, it

would appear that the 'discovery' rubric is misleading as applied to the laboratory portion of these materials" (p. 198).

Herron characterized the Physical Science Study Committee (PSSC) materials as relying almost exclusively upon an implicit presentation of scientific enquiry (p. 198) and picturing ". . . a universe governed throughout by fixed and unchanging laws which it is the difficult business of physics to uncover. . ." (p. 199). Laboratory activities are designed to establish a pattern of movement from familiar to unfamiliar and most are intended to precede the textbook and class discussion.

Herron developed a device for analyzing laboratory materials based on the levels of openness and permissiveness in an inquiring laboratory as spelled out by Schwab in "The Teaching of Science as Enquiry." Herron added a zero level. Herron's model is similar to that of Pella (1961), illustrated earlier in this paper, and appears as follows:

Level	Problem	Methods	Answers
0	Manual	Manual	Manual
1	Manual	Manual	Student
2	Manual	Student	Student
3	Student	Student	Student

Using this model, Herron analyzed 52 PSSC laboratory activities. He judged 38 (nearly 80%) to be at the 0 level, 11 at level 1, 2 at level 2, and none at level 3. From these data, Herron concluded ". . . that students in PSSC physics courses are probably never asked to attempt to formulate a problem or hypothesis and rarely, if ever, asked to devise their own procedures for collecting relevant data" (p. 201).

Herron, quoting from BSCS materials, identifies the goal of the Blue Version of the course as that of helping the student "obtain some understanding of the nature of science as a vigorous interaction of facts and ideas" (p. 201). However, Herron says, these ideas are not the prevailing structures Schwab has in mind but refer to tentative solutions or hypotheses which become theories if they stand up under repeated testing. Although laboratory work is a major part of the BSCS course, there is a lack of emphasis on an ideational factor and, thus, the origin of scientific problems is "shrouded in mystery" with ". . . no light shed on the process through which problems are formulated . . . " (p. 202)

The laboratory guide for the Blue Version of BSCS contains 62 separate exercises, according to Herron. Many of these exercises have several subparts. In a school with only single periods for biology, about one-third of the school year would be spent in the laboratory, according to Herron's

calculations. Allowing for time taken from class for other school activities (assemblies, etc.), the percentage of time for the laboratory portion of the course is increased. Teachers are frequently motivated by the belief they must cover the book and so Herron considers that such coverage and emphasis on enquiring activities are mutually exclusive possibilities (p. 203).

Using his four-point scale model to analyze the BSCS laboratory activities in the Blue Version, Herron found 45 of the 62 activities to be at the 0 level (no openness), 13 at level 1, four at level 2, and none at level 3 (p. 203). He also reminded the reader that whether students ever get to the level 1 or level 2 activities is dependent on the teacher.

Because the teacher, with his/her philosophy for teaching science, is the deciding factor, Herron was interested in teachers' views of scientific enquiry and their perceptions of the courses they taught. ". . . By the intellectual milieu he fosters, by the conceptual contexts he engenders in the minds of his students, indeed, by virtue of the topics he emphasizes (and tests for) and those he does not, he is in a position to either amplify or short-circuit the purposes of those who developed the course materials" (p. 204).

Herron interviewed 49 teachers from 20 different states and one teacher from Canada. Twenty-two had attended an institute designed to acquaint them with the "new" courses they were teaching; twenty-eight had not. The sample included 17 physics teachers, 16 biology teachers, and 17 chemistry teachers. Based on their responses, teachers were placed in one of five categories: (1) exhibiting an almost total orientation toward the content of the textbook and showing a lack of concern for any other dimension in the materials; (2) using terms such as "enquiry," "models," or the "scientific method" but perceiving these terms as related mostly to the knowledge dimension of enquiry; (3) making fairly coherent but very general references to scientific enquiry with total lack of reference to any ideational factor and the apparent absence of any systematic relationships between the variables they injected into the conversation; (4) verbalizing concerning scientific enquiry comparable to the level of the materials they were teaching; and (5) exhibiting the ability to view the science materials in a larger context, to go significantly beyond the level of discussion of the course materials themselves. Only two teachers were placed in this fifth category (pp. 206-208).

Herron contended that his data ". . . raise serious questions concerning the effectiveness of reorientation programs for teachers in awakening potential users of curricular material to the importance and relevance of a frequently stated curricular objective -- that of bringing students to some level of competence in understanding the nature of scientific enquiry . . . " (p. 209).

Herron described the 50 teachers in his sample as being impressed by the fact that the impetus for the new science materials originated with eminent scientists. If such persons were involved, why should the validity of the materials be doubted? Herron spoke of the "missionary zeal" toward the materials. He also identified another factor that complicates the

picture. The new materials advocate investigation and enquiry in the laboratory. Teachers attending institutes designed to prepare them to teach these new materials are "lectured to" which renews their exposure to college (science) teaching as "telling." Setting up a model in which science at the college level is taught by lectures and then expecting the teachers to return to their classrooms and promote investigation by students appears highly questionable (p. 211).

In summary. It would seem that we face a large number of problems, or one large problem with many aspects, relative to the role of the laboratory in science. We must overcome, or work within, financial and time constraints; we must improve the preparation of science teachers so they are competent to use the laboratory effectively; we must be more critical of the materials we use in teaching science; and we must adopt a teaching model other than the one by which we were taught science as college students. What support, if any, does science education research completed in the last two decades provide?

THE USE OF THE LABORATORY IN SCIENCE TEACHING: SOME CURRENT RESEARCH

Journal articles, research reports, papers presented at professional association meetings, and abstracts from Dissertation Abstracts International were the sources of information used for this portion of the review. As other reviewers have found, the majority of the research was of the doctoral dissertation variety. Several of the journal articles were also based on dissertation research, resulting in duplication in the reporting. The educational levels involved were primarily secondary school and college, with only a few of the studies reporting the involvement of elementary school pupils.

Rather than arbitrarily taking the five categories of objectives for laboratory teaching listed by Shulman and Tamir (1973) (i.e, skills, concepts, cognitive abilities, understanding the nature of science, and attitudes), the reviewer decided to look at the dependent variables identified in the studies to see if these might form natural clusters. Not surprisingly, since some of the same studies were reviewed by Shulman and Tamir for the "Second Handbook of Research on Teaching" (1973) as were analyzed for this publication, the clusters identified resemble the five categories listed earlier in this paragraph.

Investigators appeared to look at the influence of the laboratory on (1) achievement; (2) attitudes; (3) reasoning, critical thinking, scientific thinking, cognitive style--which could be termed "cognitive abilities"; (4) understanding science; (5) science processes; (6) laboratory skills or manipulative skills; (7) interests; (8) dogmatism; (9) retention in a science course; and (10) the ability to do independent work.

Several investigators looked at more than one dependent variable. The idea seemed to be that if a population were available to be sampled and "treated" in some manner, it was wise to study as many variables as possible. This is in contradiction to some of the earlier research on the laboratory in which the reviewers expressed disappointment that only one or two factors were studied per investigation. One of the objectives of doing this review, whether explicitly stated in the introductory section or not, was to identify those studies in which positive results were found. "Positive" may be interpreted to mean in support of the use of the laboratory and at a level of statistical significance. In order to maintain some degree of objectivity, those investigations in which the results favored some condition other than the use of the laboratory will also be reported. There seems to be little to gain in scrutinizing and describing, in this review, those studies in which no significant differences were reported. Results will be discussed as they relate to the dependent variable being considered so the reader will find the same author being cited in more than one portion of this section of the review if he/she examined more than one dependent variable.

TABLE I
VARIABLES INVESTIGATED RELATIVE TO THE USE OF THE LABORATORY IN SCIENCE TEACHING

Dependent Variable	Total Studies	Favored Lab	Favored Other	NSD	Mixed Results
Achievement	87	8	4	72	3
Attitude	32	5	1	21	5
Cognitive Abilities	25	7	2	14	2
Skills: laboratory manipulative	19	6	0	11	2
Understanding Science	11	2	0	7	2
Science Processes	8	1	0	5	2
Interests	6	0	0	6	0
Independent Work	2	0	0	2	0
Retention in Course	1	0	0	1	0

Achievement

Even the eight investigations identified, in which results favoring the laboratory were found, do not constitute overwhelming evidence in its favor when achievement is considered. Dickinson (1976) worked with community college students enrolled in general education biology in three situations: lecture-laboratory, lecture-recitation, and lecture-only. It is assumed that only the group termed "lecture-laboratory" was involved in the laboratory, as described within the confines of the abstract. When results were compared on the Nelson Biology Test and an investigator-designed test, the lecture-laboratory group scored higher on both tests than did the lecture-only group. The lecture-laboratory group did not significantly differ from the lecture-recitation group on the Nelson Biology Test and had significantly different scores on the investigator-made test when SCAT scores were used as the covariate.

Grozier (1969) worked with college general education science classes, using the laboratory vs. no laboratory. He found no significant differences in achievement -- except for students who pretested below the median. These students acquired significantly more material with the laboratory. The use of the laboratory also helped male students develop the ability to interpret data.

Gunsch (1972) used the curriculum Physical Science for Nonscientists (PSNS) with some freshmen enrolled in a physical science course and compared their progress with that of other freshmen enrolled in the conventional lecture-demonstration physical science course. He reported that the PSNS students did better on the two investigator-designed achievement tests used in his study.

Toohey (1964) looked at the effects of a laboratory course in science as compared with a lecture course for ninth grade students enrolled in general science or earth science. (The control group had no science.) Toohey reported definite advantages in learning and retention when earth science was taught by the laboratory method. He advocated that, if general science were to be retained in the junior high school, it, too, should be taught by the laboratory method.

Napier (1969) and Lucow (in the 1953 USOE publication) both investigated the effects of the science laboratory as compared with the use of the textbook. Napier, working with high school biology classes, found no significant differences on factual knowledge between groups although there were higher individual scores on measuring understanding of biological concepts and the interpretation of biological data for the group using the laboratory. Lucow worked with high school chemistry students, categorizing them as college preparatory or general education. He reported that, for the college preparatory group, both methods produced statistically significant increases in variation but the use of the laboratory produced greater increases.

Disinger (1971), in a study of the development of junior high school science students in specified cognitive and affective areas, reported that students appeared to learn more with laboratory activities than without them. Anderson (1949), in a survey of a random sample of 56 high schools in

Minnesota, reported that students in biology and chemistry did significantly better on the final examination in each subject if they were enrolled in those schools classified in the upper one-fourth of the state distribution of number of laboratory hours per student per year rather than in the lower one-fourth.

Boghai (1979) studied college chemistry classes in which the laboratory preceded discussion vs. those in which the laboratory followed the discussion. He found that having the laboratory first resulted in superior achievement and that low aptitude students made significantly better academic progress under this method.

Steele (1975) looked at the effects of self-pacing in physics courses for non-science majors and reported that the scores of the students in the self-paced laboratory activities group were significantly different, at the .05 level, from those in the conventional approach to the laboratory.

Namek (1968) compared high school chemistry students enrolled in what he termed an integrated approach to the laboratory vs. those in the conventional laboratory method and reported mean achievement scores significantly different in favor of the experimental group. Boeck conducted a study, reported in the fifth volume of the "Curtis Digests" (1971c), in which he compared the achievement of high school chemistry students using the inductive-deductive approach as compared with the deductive-descriptive approach. He reported that the inductive-deductive method was superior in promoting the knowledge of and ability to use the scientific method.

Four investigators studying at achievement found results which favored some method of instruction other than the laboratory. Townes (1976) looked at college physical science classes in which data were collected by a vicarious method in which the students saw 2x2 colored slides and listened to cassette tapes as compared with other groups using the conventional laboratory. The performance of the vicarious group exceeded that of the conventional group on all three criterion instruments used in the study.

M. O. Smith (1972) also used a vicarious method of instruction in his research with college physical science students. The vicarious method is not described in the abstract of his research. Smith reported that the vicarious method of instruction was significantly more effective in promoting achievement than was the conventional one.

A third investigator also used a method which might be termed vicarious although he did not call it that. Brosius (1965) worked with high school biology students. One group viewed color sound films and the other group performed dissections on earthworms, crayfish, perch, and frogs. The films were judged to be superior to the actual dissection activities in teaching factual knowledge.

Andriette (1970) looked at the effects of teacher-demonstration vs. small group laboratory methods on cognitive learning of above-average seventh grade students. He found no significant differences at the knowledge level but the achievement at the comprehension level was significantly greater for the students in the teacher-demonstration group.

Another study in the achievement area deserves mention, not so much for the data reported from the experimental treatment as for the side-effects.

Baxter (1969) worked with general education physical science classes. Some received what he termed a subject-centered treatment; some, a historical treatment; and some, the historical treatment plus the laboratory. There were no significant differences in achievement. However, the students in the laboratory group thought the laboratory experiences had helped them to better understand the concepts and principles involved. And, the students who had not participated in the laboratory were of the opinion that if they had had laboratory activities, they, too, would have been better able to understand the concepts and principles. (Another example of the laboratory "mystique"?)

Although the various researchers purported to study the effects of one treatment or another on achievement, there are so many differences among studies or the way in which they are reported, that generalizations are not easy to come by. The most obvious one appears to come from the "negative" findings--vicarious experiences can promote some types of achievement as effectively as laboratory activities can. Laboratory activities appear to be helpful to those students who are rated as medium or low in achievement on pretest measures, at least in two studies [Boghai (1979), and Grozier (1969)].

Attitudes

Ramsey and Howe (1969a,b,c) in a review of research on instructional procedures said that, when considering attitudes, we should be careful to distinguish between scientific attitudes and positive attitudes. Scientific attitudes are characterized by accuracy, intellectual honesty, open-mindedness, seeking cause and effect relationships, and the ability to suspend judgment. Positive attitudes are feelings, opinions, emotions, and appreciations (p. 66). It was not always possible to determine which kind of attitudes investigators were studying in the research reviewed.

The feelings/emotions/opinions type of attitudes were probably those measured by King (1975), who reported students had more favorable attitudes toward the audio-tutorial approach to college biology than those non-majors in the traditional classes. Dickinson (1976) also looked for attitude changes and found more favorable ones in students in lecture-laboratory and lecture-recitation classes than among students in the lecture-only classes in general education biology. Steele (1975) looked at attitudes toward science instruction and found these to be significantly different for the students in the self-paced laboratory group in his study. Gunsch (1972) looked at attitude changes toward science and found more favorable changes among PSNS students than among those students enrolled in the traditional physical science courses. Campbell (1978) found students in a personalized system of instruction approach to beginning college physics had attitudes that differed significantly from the control group in three of four areas and were not as likely to withdraw from the course as were the control group students.

Johnson et al. (1974) looked at the effects of different teaching situations on the attitudes of sixth grade students toward science. They found that those students who used materials to answer questions developed more positive attitudes about science than those who did not. No significant loss of positive attitudes was found when the textbook was mixed with materials-oriented laboratory activities, causing the authors to question whether the instructional pendulum has swung too far in terms of all activities and the effect of activities on attitudes (p. 55).

Balcziak's study, reported by Brown and Blackwood (1955), contained the statement that students made significant gains in "science attitude" only under the individual laboratory method, as compared with the demonstration or demonstration-individual laboratory work methods (pp. 143-144). "Science attitude" is hard to classify using Ramsey and Howe's categories.

Coulter (1966) talked about "scientific attitudes," which apparently belong in the first of Ramsey and Howe's two categories. He used three instructional methods: inductive laboratory experiments, deductive laboratory exercises, and the demonstration of inductive experiments. Coulter found the inductive methods produced significantly greater attainment of the attitudes of science. Allison (1973) looked at attitudes toward science, breaking these into intellectual and emotional components and a total score. He found that students using inquiry laboratory activities in an introductory college chemistry course showed significant improvement in their intellectual attitudes, although there were no significant differences in the total score or in the emotional component of the attitudes. Boeck, in the study previously mentioned in the Achievement section, reported that the inductive-deductive approach was superior for the development of scientific attitudes.

Cravats (1969) investigated the use of laboratory exercises with low IQ ninth grade students. Although he concluded that the teachers were the most significant factor in his study, Cravats also reported that those students who had completed the laboratory activities developed better attitudes toward school.

The disappointing study in this group is the one by Grozier (1969) who worked with general education science for non-majors. He reported that the students who did not have laboratory experiences improved in their attitudes toward science while those enrolled in the laboratory sections decreased in positive attitudes.

Considering the attitude studies with positive findings and those with mixed results again produces a lack of generalizations. More investigators looked at the feeling-kind of attitudes than at scientific attitudes. Is this a reflection of Hurd's verbalized dilemma about teaching science for the citizen or for the scientist? Are these two aims really that incompatible for the same class?

Cognitive Abilities

The cognitive abilities mentioned in the various research studies were reasoning, critical thinking, scientific thinking, and cognitive style. A few researchers looked at cognitive development, according to Piaget, either to study the effect of laboratory activities on this development or to differentiate between formal operators and concrete operators in the science laboratory.

Dorrance (1976) studied community college students enrolled in an introductory biology laboratory course. Students received either a lecture and structured laboratory or lecture with structured demonstration, with a lecture-only group serving as the control. The laboratory method of instruction proved superior to the demonstration method on a 40-item test on cognitive skills based on Bingman's (1969) (BSCS-McREL) analysis of the processes of science.

Holloway (1976), in a study of the effects of open-ended laboratories on critical thinking abilities and attitudes toward science, reported that he found significant differences in both variables. Unfortunately the abstract of his dissertation does not identify in whose favor the differences were.

Mandell (1967), Rogers (1972), Allison (1973), and Sorensen (1966), also investigated critical thinking. Mandell studied the use of college biology laboratories to develop or increase critical thinking. Students were either in a control group or in a critical thinking laboratory. Both groups increased in critical thinking, with the increase being significant for the experimental group at the .10 level. The experimental sub-group, with IQ's below the mean, had significant gains in critical thinking, although a similar sub-group of control group students did not. Mandell suggested that caution should be used in interpreting the results of his study because of the low number of cases involved (17 in the control group, 23 in the experimental). Rogers worked with 103 freshmen in a college general studies science course. The treatment Rogers used was not described in the abstract of his study but it must have involved the use of the laboratory as opposed to discussion, based on his problem statement as well as on his conclusions. He concluded that if critical thinking were to be promoted, laboratory investigations were significantly superior to the discussion-centered instruction. Sorensen, working with 20 randomly selected high school biology classes (with 10 of these randomly selected to be the experimental group), found that the lab block classes constituting the experimental group exhibited significant growth in critical thinking ability at all IQ levels.

Allison compared the inquiry laboratory approach with a "structured" approach in an introductory college chemistry course. He found no significant differences between the experimental and control groups in critical thinking skills. However, the students in the inquiry approach did exhibit significant improvement in critical thinking skills.

Palmer (1967) looked at the role of the laboratory in conceptualization, using 36 students randomly selected from three classes studying the Green Version of BSCS biology. These students were involved in a series of

structured interviews. Palmer reported that the laboratory did not directly contribute to the acquisition of factual knowledge related to conceptualization but that it did contribute significantly to those mental abilities and processes requisite to conceptualization. The laboratory appeared to play an important role in developing mental abilities such as critical thinking and reasoning.

Godomsky (1971) designed a study with three problems: to determine the effectiveness of (1) experiments without explicit directions, (2) programming of prerequisite capabilities for each of four basic experiments, and (3) using performance problems programmed for computer evaluation. One treatment group and three control groups were involved. Godomsky concluded, after studying student data from performance tests, that the designed laboratory instruction did increase students' problem-solving ability in physical chemistry and that the laboratory can be a valuable instructional technique in chemistry if the experiments are genuine problems without explicit directions.

Tamir and Glassman (1971) compared BSCS and non-BSCS students' performance on an inquiry-oriented performance laboratory test. They found that the BSCS students did significantly better, due mainly to superiority in reasoning and self-reliance. The researchers concluded that BSCS students have a distinct advantage in solving open-ended problems using experimental procedures in the laboratory.

Campbell (1978) evaluated a Piagetian-based model for developing materials and instructing the laboratory portion of a beginning college physics course. Students (N=55) in two different states were involved. Although there were no significant differences in learning physics content, there was significant improvement in the use of more formalistic reasoning abilities for the students. Campbell's "learning cycle" model involved three separate but interrelated activities: exploration, concept invention, and concept application with 10 "laboratory intervention periods."

Ward (1979) investigated the interaction among level of intellectual development, design of laboratory exercises, and comprehension of ideas requiring either concrete or formal operations logic. Students in introductory college chemistry for non-majors were randomly assigned to treatment or control groups, with the treatment group using instruction materials based on the learning cycle (not further described in the abstract). Formal students outperformed concrete students on both types of test items: those requiring concrete thought and those requiring formal thought. The limited exposure to the learning cycle did not appear to improve either student group on test items requiring formal thought. Ward expressed the concern that intellectual development was an important factor in the design of general chemistry instruction. However, methods for altering instruction to make it amenable to concrete students and still include all the concepts necessary in a first college course in science are yet to be developed.

Two investigators found results that did not support the laboratory in the development of critical thinking ability. M. O. Smith (1972) found that

students who gathered data in college-level general physical science by vicarious experimentation were better in the development of critical thinking ability than were those who performed conventional experimentation. Edgar (1969) worked with 6 teachers and 148 tenth grade college preparatory biology students in his analysis of the effects of laboratory-centered instruction on the improvement of student critical thinking skills and the development of positive student attitudes toward biology. (He found no significant differences related to attitude change.) Both the BSCS biology students and those in "conventional" biology showed significant improvement in critical thinking but the non-laboratory group exhibited more improvement than did the laboratory group.

The same situation prevails in this cluster as in the two previous ones: the majority of the studies reported no significant differences. However, combining those studies in which the researchers report significant differences with those of mixed results does provide some support for the idea that laboratory activities can be used to help students learn to think critically. Does this relate back to the faculty psychology idea or is it a part of being scientifically literate?

Laboratory Manipulative Skills

Two studies (Knox, Horton) that do not qualify as "recent" research contained reports on investigations of the variable of manipulative skills. These are reported in the second volume of the Curtis "Digests," first published in 1931 and reprinted in 1971.

Within the last two decades several more researchers have looked at manipulative skill development. Dorrance (1976) found the laboratory method to be superior to other methods in the acquisition of manipulative skills by community college students enrolled in biology. Allison (1973) also worked with college students enrolled in an introductory chemistry course, and reported that the inquiry laboratory experiences were significantly more effective than the structured approach in increasing laboratory performance skills.

Other investigators worked with secondary school students. Sherman (1969) investigated the relative effectiveness of two methods using laboratory-type activities in teaching Introductory Physical Science (IPS): a direct manipulative approach and an indirect non-manipulative approach. Eighth grade students of average and high ability were involved in the study. The experimental group saw a series of 2x2 colored slides of a sequence of laboratory activities which the control group performed in their classes. Sherman looked for changes in critical thinking abilities, understanding of science, academic achievement of knowledge and skills in IPS, and the development and expression of interest in science. The only significant difference he found was that the control group, using the direct manipulative approach, was significantly superior in selected laboratory skills demonstrated by their performance on a laboratory skills test Sherman constructed. [Information on this well-designed study is available as a dissertation abstract, as a report from the Wisconsin Research and Development Center (1968), and as an article in School Science and Mathematics (Pella and Sherman, 1969)].

Yagar, Engen and Snider (1969) conducted the study which Welch (1971c), in a NARST-ERIC review, hoped was the last of its type (it was not). They worked with 60 students in grade 8 in the University of Iowa laboratory school. These students were studying the Blue Version of BSCS. The students were divided into three groups: one group did 50 of the 57 experiments in the BSCS materials, one group used demonstrations (performed by the teacher or the students), and one group used discussion only. All studied the same content and took the same tests. Teachers changed groups every four weeks to counter any possible teacher effect. The investigators looked for differences in critical thinking, understanding the nature of science, knowledge of general science and biology, and the ability to use biology tools. The only variable on which there was significant difference was that of mastery of laboratory skills. The laboratory group had increased their skill in laboratory manipulations as demonstrated by performance in focusing a microscope under high and low power, the time involved in constructing a manometer, and the ability to make coacervates.

Grosmark (1973) looked at the effects of increased laboratory time in high school chemistry. Students enrolled in regents chemistry in suburban New York City high schools were randomly assigned to one of two treatments. The experimental group performed an additional chemistry experiment each week, completed in each student's free time under a modular scheduling plan. Grosmark reported that performing an additional experiment each week resulted in a significant difference in laboratory skills as shown by scores on a laboratory performance test.

Beasley (1979b) took an interesting approach to methods of increasing psychomotor performance. He looked at the effects of physical practice and those of mental practice, working with students enrolled in introductory college chemistry. Although Beasley failed to find significant differences among his various treatment groups, he found that when each treatment group was compared to the control group, the treatment group was significantly better. He concluded that some form of planned practice of psychomotor skills -- physical, mental, or physical and mental -- is likely to be associated with superior laboratory performance.

Coulter (1966) compared the effects of inductive laboratory experiments, deductive laboratory exercises, and demonstrations on a number of variables, one of which was laboratory techniques. Coulter found that the laboratory treatment groups were significantly different from the demonstration group on a test of laboratory techniques. Most researchers would have stopped there, but Coulter did not. He provided the demonstration group with a five-period laboratory technique instruction course and found the demonstration group to be as adept in laboratory techniques as were the laboratory groups.

Apparently the opportunity to learn by doing does produce significant results when manipulative skills are investigated, as indicated by the studies reviewed. However, Coulter's study provides some new questions for investigation: How much hands-on experience with laboratory materials and equipment is needed in order to equate groups? To produce a significant difference?

Understanding the Nature of Science

If science educators are concerned with producing scientifically literate citizens, it would seem that more researchers should be investigating methods for increasing students' understanding of the nature of science and of the scientific enterprise. Although 11 studies were located in which this variable was studied, this is a small number when compared to the 85 studies on achievement.

Stekel (1971) compared the effectiveness of two different laboratory programs in college physical science: a traditional program with a laboratory manual and a more flexible, open-ended program. In the open-ended approach students selected their own problems related to a general topic, designed their own procedures, and completed an experiment. Stekel found a significant difference ($p < .01$), favoring the open-ended group, on the understanding of actions or operations of scientists.

Whitten (1971) looked at the effects of changes in a general education laboratory physical science course. He found the experimental group made significant gains on the Test of Understanding of Science Processes (TOUS), parts I, III, and total, as well as on the Wisconsin Inventory of Science Processes (WISP). When differences in ability, school achievement, background knowledge, or skill were covaried out, the experimental group still scored significantly higher on TOUS I, III, and total. Whitten concluded that laboratory activities had made an important contribution to the TOUS scores.

Sorensen (1966) reported that high school students who had performed two BSCS lab blocks (Plant Growth and Development, Animal Growth and Development) exhibited significant growth in their understanding of science at all IQ levels.

Crawford and Backhus (1970), studying different approaches to laboratory work in a survey science course for non-majors, set up three treatments: scheduled laboratory, free laboratory (students came when they wished within the times the laboratory was open), and take-home laboratory kits. In the second experimental period of their study, the researchers found that the free laboratory and take-home laboratory groups scored significantly higher than the scheduled laboratory students on the TOUS. Crawford and Backhus speculated that the first two situations may have emancipated the students to such an extent that they investigated further than the researchers expected.

Other Variables Investigated

Science processes. Many investigations which include this variable show the effect of the NSF science course improvement projects. Serlin (1977) talked about a discovery laboratory in college physics. In his terms, such a laboratory would emphasize hypothesizing, experimenting, and inferring rather than fact-gathering and principle verification. Serlin established three criteria for the discovery laboratory: (a) activities be

matched to the developmental stage of the learner, (b) guidance be provided by the use of advance organizers, and (c) further guidance be provided by describing the nature of science as a discovery activity for the students. Although Serlin's concern was for the improvement of physics laboratories for undergraduates, he and a colleague worked with students in a calculus course which was a prerequisite for the undergraduate physics course.

Two experimental groups and one control group were involved. Students were provided practice in the processes of science, problem-solving, and setting up and applying standards of evaluation. With verbal SAT scores used as a covariate, Serlin found that the discovery laboratory was effective in increasing students' science process skills ($p=0.05$).

Robertson (1972) attempted to identify differences between students taking Introductory Physical Science (IPS) and those in general science in the manipulation of basic laboratory equipment, graphing data, and the interpretation of data. He found no significant differences in the manipulative area. However, the IPS group was significantly better than the general science group three of the six times a table of data was constructed and graphed and significantly better all seven times data were interpreted in an experiment.

Hughes (1974) investigated the effect of computer-simulated experiments on attainment of science process skills by high school physics students. Hughes used three groups: the laboratory group which did the experiments in the traditional manner, the laboratory-computer group which did one trial experiment and then used computer simulations to get data for analysis, and the computer group which got instruction sheets describing the experiments but used simulations for their data. The laboratory group and the laboratory-computer groups had higher mean process test scores than did the computer group but these differences were not significant. Hughes concluded that maximum benefits were realized from computer simulated experiments only after a first-hand laboratory experience.

The study done by Hughes, combined with the study by Coulter (1966), again raises the question of how much laboratory experience is necessary to produce a desired change in psychomotor skills or in use of the processes of science.

Interests. Although this is another assumption science educators cherish (participation in laboratory activities develops interest in science or increases those interests already present), the six studies related to this variable all produced no significant differences.

Ability to work independently. This area also failed to produce results of significant differences, although Tamir and Glassman (1971) characterized BSCS students as being more self-reliant than were non-BSCS pupils.

Dogmatism. This variable might have been forced into the cognitive cluster or considered as an attitude, but it appears to differ from those factors and was treated separately. Sorensen (1966) found that the high school biology students who had participated in the two BSCS laboratory

blocks became significantly less dogmatic, with the higher IQ students less dogmatic than those of lower IQ. There was no significant change for the lecture-demonstration group in his study.

Retention in course. This, again, may be a function of attitudes. Campbell (1978) found that students in a beginning college physics course based on a Piagetian model were less likely to withdraw before the end of the semester, but he did not indicate this finding was at a level of significance.

In summary. If what we investigate is what we value, it would appear that increasing achievement is of most worth. If that is true, it is unfortunate that few of the studies in which achievement was a dependent variable contained results of significance in favor of the use of the science laboratory. The next highest value appears to be placed on developing attitudes -- in large part attitudes favorable to science rather than scientific attitudes. Third place appears to go to variables of the cognitive variety that differ from achievement -- ability to reason and, to think critically as two examples of this area. Next we strive for the development of manipulative skills related to the laboratory, the area in which we appear to have the most likelihood of success. Eventually we worry about whether the laboratory helps our students to understand the scientific enterprise -- an objective that might be assumed to rank higher, based on the concern for scientifically literate citizens and for pupils who are expected to experience science as a practicing scientist does through involvement in enquiry. In all of these first five areas, "no-significant-difference" studies predominate.

Another Look at the Research

Because the research does not provide overwhelming support for teachers of various age groups who are faced with pressures to decrease, or eliminate, laboratory work and who wish to retain the laboratory, the decision was made to look at the competition the laboratory faced in various studies, as well as which instructional method "won." The comparative studies were divided into those in which the use of the laboratory was compared with some other instructional method or methods, and those in which the "traditional" laboratory was compared with some modification or version designed to improve instruction.

Laboratory vs. other method(s). Studies within this category have been further classified, as follows:

a) Laboratory vs. no laboratory

Investigator	Used	Result
Holloway (1976)	open-ended laboratory vs. no laboratory	NSD on attitudes, thinking
Whitney (1965)	no laboratory for one semester	NSD on any of 11 variables

Investigator	Used	Result
Andriette (1970)	small group laboratory teacher-demonstration	teacher-demonstration better at comprehension
King, C. R. (1969)	laboratory vs. demonstration	lab students "do better" on application of laboratory experiences
Grozier (1969)	lecture-laboratory vs. lecture-only	students without lab improved their attitude toward science; students pretesting below median acquired significantly more material with lab
Bailey (1965)	laboratory vs. enriched lecture-demonstration	NSD on chemistry achievement
Rogers (1972)	laboratory vs. discussion	lab group significantly superior on critical thinking
Bradley (1963)	laboratory vs. lecture-demonstration	NSD on achieving the objectives of general education
Strehle (1964)	laboratory vs. lecture-discussion	NSD on achievement
Toohey (1964)	laboratory vs. lecture	lab group had definite advantage on learning and retention
Cravats (1969)	laboratory vs. lecture	students having lab work had better attitudes toward school
Napier (1969)	laboratory vs. textbook	neither method increased factual knowledge; lab method "seemed" to generate more student interest, enthusiasm
Saunders & Dickinson (1979)	lecture-laboratory vs. lecture-only	lecture-only least effective method
Bybee (1970)	laboratory vs. no laboratory	NSD on achievement

Godomsky (1971)	laboratory vs. no laboratory	problem-solving ability was greater for laboratory group

In this cluster, the use of the laboratory appeared to help in the development of critical thinking (Rogers), in learning and retention (Toohey), and in generating more favorable attitudes toward school (Cravats), as well as in producing student interest and enthusiasm (Napier). It also helped students pretesting below the median to learn more material (Grozier), as well as enabling students to apply laboratory experiences (C. R. King).

b) Laboratory vs. two other methods (which may or may not involve lab work)

Investigator	Used	Result
Dorrance (1976)	lecture-structured lab vs. lecture-structured demonstration, lecture-only	lab method superior in acquisition for manipulative and cognitive skills
Dickinson (1976)	lecture-laboratory vs. lecture-recitation, lecture-only	NSD on achievement, attitude
Paulsen (1979)	lecture-delayed lab vs. lecture-laboratory, lecture-only	NSD for group comparison on achievement; lecture-delayed lab group had higher score on lab exam, higher course grade
Baxter (1969)	historical + laboratory vs. subject-centered, historical approaches	NSD on achievement, TOUS. Students in lab group "thought" lab helped them; those in other groups thought the lab experiences would have helped them
Coulter (1966)	inductive laboratory vs. deductive laboratory demonstration of inductive experiments	attitudes significantly different for two inductive groups; lab groups significantly better on lab techniques test (but, only 5 sessions of lab work brought demonstration group to equal adeptness)

Blomberg (1974)	laboratory vs. reading + lecture, audio-visual methods	NSD on achievement
Costa (1974)	laboratory vs. vicarious experimentation, descriptive narrative methods	NSD on TOUS, attitudes; all three methods produced increased achievement
Hughes, W. R. (1974)	laboratory vs. laboratory + computer, computer simulation only	NSD on process test scores
Spreadbury (1969)	laboratory vs. Suchman inquiry session, teacher-demonstration	NSD on achievement; on retention test, two groups lacking laboratory did significantly better
Dearden (1959)	laboratory vs. demonstration, workbook, report	NSD on knowledge, attitude, scientific thinking
Yager et al. (1969)	laboratory vs. demonstration, discussion	NSD on achievement, TOUS, critical thinking, attitude toward science.
Raghubir (1979)	laboratory-investigative approach vs. lecture-laboratory	experimental group significantly better on pre/post gains for cognitive factors, associated attitudes.

When investigators have several treatments to handle in the same study, more findings of no significant differences seemed to appear. The laboratory did appear to be of use in developing manipulative skills (Dorrance, Coulter, Yager et al.) but this difference may not have been caused so much by the treatment as by the withholding of it, as Coulter's findings seem to indicate.

c) Laboratory via a specific curriculum project

Investigator	Used	Result
Gunsch (1972)	PSNS vs. traditional lecture-demonstration	PSNS students achieved better, had more favorable attitudes

Edgar (1969)	BSCS vs. non-BSCS	Non-BSCS group did better on critical thinking measure
Sullivan (1972)	IPS vs. "control classes"	NSD for psychomotor abilities
Robertson (1972)	IPS vs. general science	NSD in manipulative skills; IPS group better at graphing, data interpretation
Johnson et al. (1974)	ESS vs. traditional textbook, textbook + materials	students using materials had significantly more positive attitudes about science than those using only the textbook

This cluster would provide some support for the use of science curriculum improvement projects if achievement of older students is desired (Gunsch). If process skills are an objective, then these materials are also helpful (Robertson). Project materials also engender positive attitudes (Gunsch, Johnson et al.). They do not appear to promote psychomotor skills (Sullivan, Robertson) but this result may lie more with the physical development of the student groups involved than with the materials used. (This last supposition is not based on a review of the research but on a number of years of junior high school science teaching experience.)

d) Other variations

Investigator	Used	Result
Boghai (1979)	laboratory-discussion vs. discussion-laboratory	laboratory-first promotes superior achievement, especially for low aptitude students
Reach (1977)	theory-proving lab vs. skill development lab	theory-proving lab for learning, when lab questions were excluded from the analysis
Simpson (1970)	workbook experiment vs. workbook or own experiment, no experiments	NSD on any general education objectives
Emslie (1972)	laboratory-theory vs. theory-laboratory	NSD on achievement

Simpson & Gallentine (1971)	analytic vs. representative drawings in lab	NSD for academically talented pupils. lower ability seventh graders did better on subsequent tests if they had used the analytic method

At first glance, one might think that the laboratory-discussion study by Boghai and the laboratory-theory study of Emslie should have been expected to produce similar results. Although the two studies appear to have a common element (i.e., sequencing of instruction) they differ in educational level and content involved, as well as in actual methodology employed in instruction, evaluation, and data analysis.

Traditional laboratory vs. some modification. The researchers whose studies are reported in this section did not appear to be questioning whether or not the laboratory should be used but were interested in determining if it could be modified so that its use would be more successful in achieving certain outcomes. Again, studies within this category have been placed in subgroups, as follows:

a) Laboratories involving some degree of student control of instruction

Investigator	Used	Result
King, T. J. (1975)	audio-tutorial	attitude toward biology more favorable for experimental group
Mitchell (1971)	audio-tutorial	NSD for knowledge, critical thinking (students in experimental group reported liking method during study but, later, recommended conventional lab method for future students)

Within this cluster, eight researchers reported no significant differences while three reported results favoring the experimental group, with two of these three indicating the results were at a level of significance.

b) Studies using some form of media (films, slides, film loops)

Investigator	Used	Result
Brosius (1965)	color, sound films	films superior to conventional dissession in teaching factual knowledge, NSD on other variables

Driscoll (1974)	color video labs	NSD on chemistry achievement
Hughes, J. E. (1972)	lab method films	NSD on achievement
Sherman (1968)	2x2 colored films	significant difference for lab group only on manipulative skills variable
Benzvi et al. (1976)	filmed chemistry experiments	NSD on variables
Hamilton (1967)	single concept filmloops	NSD on two process skills (Students "seemed" more highly motivated by lab instruction)
Townes (1976)	2x2 colored slides, cassette tape	experimental group superior on achievement in physical science, competence in use of science processes
Calentine (1969)	2x2 colored slides + the microscope vs. microscope only	control group achieved significantly better
Dubravcic (1979)	chemistry lab films	NSD on achievement

This cluster of studies appears to provide evidence that if alternatives to conventional laboratory instruction are no better than the conventional methods, at least they are no worse. The study by Brosius would support the use of films as a substitute for dissection in biology as would that of Townes for instruction in general education college physical science. In Calentine's report, he hypothesized that the experimental group probably did not have enough time to study both the microscope slides they were manipulating and the colored projections of these slides and so chose to concentrate only on the actual slides rather than their projected images. In Sherman's study, it was reported that the indirect manipulation IPS group of students also showed improvement in manipulative skills even though they were restricted to viewing 2x2 colored slides. However, the manipulative group's improvement was significantly greater than that of the non-manipulative group.

c) Studies involving simulations

Investigator	Used	Result
Cavin (1977)	computer simulations	NSD in performance scores

Jones, J. E. (1973)	computer simulations	NSD in attitude scores toward science course, toward the laboratory
Lunetta (1972)	computer simulations	all groups made significant increases from pre- to post-tests
Smith, M. O. (1972)	vicarious experimentation	vicarious group scored better on critical thinking, achievement

In addition to the studies listed above, the study by W. R. Hughes (1974) also involved computer simulation. One of the three groups in the Hughes study performed only one laboratory activity before spending the rest of the time working with computers. Hughes' concluding remarks seem to indicate that he considered that single experience important in enabling students to gain maximum benefits from computer simulations.

Cavin's study (1977) involved four pairs of simulated and conventional laboratory experiments. Comparisons were made on the basis of achievement on written tests, time required to do the experiment, time required to do the calculations for the experiment, and - in one case - performance on a practical test over the use of an instrument. She reported that although there were no significant differences on the scores of the performance test, the laboratory group took the performance test in significantly less time. Students who did the simulated experiment performed significantly better (than those in the lab) on some of the written achievement tests and did the experiment in a shorter time in two cases.

Jones (1973) reported that, at the end of the experiment, the experimental group of students had a significantly more positive attitude toward using the computer as an instructional aid than did the control group.

Lunetta (1972) used two experimental groups and one control group in his study. Group I used film loops and computer interactive dialogs. Group II used film loops and simulated data and problem sheets. Group III performed the PSSC experiments in the laboratory. All three groups learned, at a significant level, in this order: I, II, III. Group III spent the most time in instructional activities. Lunetta concluded that while his study provided evidence that learning through the computer simulation dialogs was more effective and efficient than learning the same concepts with real laboratory materials, the evidence did not indicate that simulations should replace all first-hand experience with real materials. He suggested that the computer had potential use for individualizing instruction.

d) Studies emphasizing inquiry/enquiry, discovery

Investigator	Used	Result
Serlin (1977)	discovery lab	successful in increasing process skills

Dawson (1975)	guided decision-making	NSD on critical thinking, knowledge of science processes
Mandell (1967)	critical thinking lab	significant difference in critical thinking (.10) for experimental group
Allison (1973)	inquiry lab	NSD on attitude, critical thinking; significantly more effective in increasing lab performance skills
Snyder (1961)	adding problem project	NSD on achievement
Sorensen (1966)	use of BSCS lab blocks	significant growth in critical thinking, understanding of science; significant decrease in dogmatism
Charen (1966)	MCA open-ended experiments	significantly more than one-half the students involved favored open-ended experiments
Egelston (1971)	open, inductive, discovery unit	significant differences between groups on Learning Environment Inventory
Babikian (1971)	discovery vs. expository, laboratory methods	achievement scores higher for expository and lab groups than for discovery group
Hoff (1970)	enquiry vs. lecture-demonstration, directed approaches	NSD on achievement, retention

• Even though these researchers used the terms inquiry, enquiry, and discovery, there were too many differences among the studies to permit comparisons and generalizations.

e) Other variations on the theme

Investigator	Used	Result
Namek (1968)	integrated lab vs. traditional approach	mean achievement scores in experimental group significantly higher than in traditional; NSD on understanding the processes of science

Spears and Zollman (1977)	unstructured lab vs. structured lab	structured labs appeared to benefit students who were not formal operators
Grosmark (1973)	extended lab time	NSD on achievement, attitude; additional time significantly improved lab skills
Smith, A. E. (1971)	extended lab problem	NSD on achievement, attitude, understanding of science
Whitten (1971)	modified course	significant gain in TOUS scores
Campbell (1978)	use of Piagetian-based model of instruction	significant improvement in use of more formalistic reasoning abilities; NSD in learning physics content
Ward (1979)	use of learning style	formal operators outperformed concrete operators

This cluster, by virtue of its miscellaneousness, contains very little that is common among studies. Three investigations did contain discussions of cognitive development as described by Piaget (Spears and Zollman, Campbell, and Ward). In the Spears and Zollman study (1977), the unstructured laboratory approach involved the specification of objectives, with the procedures for attaining these objectives left up to the students. The researchers reported that students not at the formal operations level could not devise their own experiments to solve the problems posed. In Campbell's study (1978) students were provided with learning cycles made of three separate but interrelated activities. This approach appeared to help students at the concrete operations level move toward the formal operations level. Ward (1979) wrote of a "learning cycle" (not described in the abstract) and reported that a limited exposure to this learning cycle in the laboratory did not appear to improve the performance of concrete or formal students on test items requiring formal thought.

What have we found in all this research that is of any value? This question cannot be answered without qualifying the response. What has been said by others bears repeating: the interpretation of such studies is dependent upon the assumptions made about the purposes of laboratory instruction. If the acquistion and retention of factual knowledge is desired, one procedure is probably as good as another.

However, if we believe that the student learns to understand the nature of science by "doing science," then involvement in investigation is necessary. The student needs to be involved in planning experiments,

collecting and organizing data, formulating results, interpreting findings, and subjecting these to further study. Success in such activities should be evaluated by some method other than an achievement test. (After Hurd, 1961, p. 227)

In addition to examining assumptions and objectives, the reader needs also to consider the problems involved in comparing teaching methods.

Problems of Research on Teaching Methods

McKeachie, writing in a chapter in the "Handbook of Research on Teaching" (Gage, ed., 1963), was concerned with discussing research on teaching at the college and university level. His comments are equally relevant for research at the elementary and secondary levels involving instruction. McKeachie said,

> . . .Determining which of two teaching methods is more effective looks like a simple problem. Presumably, all that is necessary is to teach something by one method and then to compare the results with those obtained by teaching the same thing by another method . . . Unfortunately, there are pitfalls which enthusiasts for one method or another are likely to overlook. (p. 1122)

McKeachie identified six such pitfalls (pp. 1123-1124):

(1) Taking a course taught by a new method may generate excitement or hostility. The Hawthorne effect influences teachers as well as students. The treatment rarely lasts for more than one semester. What happens after the excitement fades?

(2) There is a problem of establishing a suitable control group. Can one individual really teach using two different methods and not have some aspect of one method influence the other? Is it possible to get another individual to participate as a teacher and use the method the study imposes?

(3) Conditions involved in the treatment may interfere with normal results.

(4) Biased sampling may occur in that people who sign up for the treatment are likely to be different from those who elect the traditional course.

(5) Researchers need to consider the statistical methods used to analyze the results. One should be careful to avoid concluding that one method is more effective than the other when in reality these methods do not differ significantly. It seems less likely that the researcher will make the error of concluding there is no difference in effectiveness when the two methods do not differ significantly. There is also the problem of the choice of methods of analysis: "weak statistics."

(6) There is also the problem of dealing with interactions among teaching methods, student characteristics, teacher characteristics, or other variables.

McKeachie emphasized that the major problem in experimental comparisons of teaching methods is the criterion problem. He stated, ". . .Undoubtedly, one reason for the many non-significant differences in studies of teaching is poor criterion measures. . ." (p. 1124) and warned that a careful definition of desirable outcomes does not solve the criterion problem. The measuring instruments may not be appropriate for the task to which they are applied. It is also possible that the instruments are appropriate but are not sufficiently sensitive to detect changes occuring in the period of time involved in the study.

McKeachie also pointed out that seldom do researchers follow up the students who composed the experimental group to see if the treatment has any other effects on these students in their other courses, on the faculty, or on the instructional program.

In discussing laboratory teaching at the college and university level, McKeachie reported (pp. 1144-1145):

> Laboratory teaching assumes that first-hand experience in observation and manipulation of the materials of science is superior to other methods of developing understanding and appreciation. Laboratory training is also frequently used to develop skills necessary for more advanced study or research.
>
> From the standpoint of theory, the activity of the student, the sensorimotor nature of the experience, and the individualization of laboratory instruction should contribute positively to learning. Information cannot usually be obtained, however, by direct experience as rapidly as it can from abstractions presented orally or in print. . .Thus, one would not expect laboratory teaching to have an advantage over other teaching methods in the amount of information learned. Rather we might expect the differences to be revealed in retention, in ability to apply learning, or in actual skill in observation or manipulation of materials. Unfortunately, little research has attempted to tease out these special types of outcomes. . .
>
> Whether or not the laboratory is superior to lecture-demonstration in developing understanding and problem-solving skills probably depends upon the extent to which understanding of concepts and general problem solving procedures are emphasized by the instructor in the laboratory situation.

It would appear that McKeachie also recognized the importance of the teacher in determining the outcomes of instruction. Rasmussen (1970), mentioned in the "critics" section of this review, stated that in-service teachers' behavior is determined by the structure of the program they are expected to teach. It therefore seems appropriate to look at research related to the objectives of using the laboratory in science teaching.

Research on Objectives for the Use of the Laboratory

Tamir (1976) describes four major rationales for the extensive use of the laboratory in science teaching (pp. 8-9):

1. science involves highly complex and abstract subject matter which students who are not at the formal operations level of cognitive development grasp more readily if they interact with concrete objects and have opportunities for manipulation,

2. proponents of enquiry argue that student participation in the actual collection of data and the analysis of real phenomena is an essential component of enquiry,

3. laboratory experiences are needed for the development of skills with a wide range of generalizable effects, and

4. students enjoy laboratory activities and consequently become motivated and interested in science.

Tamir cites various authors as he develops these rationales, but persons familiar with the literature will recognize the fact that many of the individuals cited are voicing personal opinions and assumptions rather than research data supporting their contentions.

Shulman and Tamir (1973), in the Second Handbook of Research on Teaching (Travers, ed.), group objectives into five categories: skills, concepts, cognitive abilities, understanding the nature of science, and attitudes. This classification is based on the literature review relative to science education in the 1960's. Again, this literature is composed of opinion articles as well as research reports; and, the research studies focused primarily on achievement of objectives rather than on the consideration of whether or not the objectives were desirable or attainable.

Shulman and Tamir wrote that they considered the ferment of science education of the Sixties to be characterized by four conceptions: (1) the structure of the subject matter; (2) the learner, his capabilities, readiness, and motives - citing the influence of both Bruner and Piaget; (3) teaching and learning: intuition, intellectual risk, discovery, and inquiry; and (4) the technology of teaching, both hardware and software (in Travers, 1973, p. 1099). Their depiction of the times and activities is an accurate one. It also, however, serves to reinforce individuals such as Hurd, Renner, and Novak who stress the need for a theory base or bases for science education.

Did any researchers confine their activities to investigating the identification of objectives for science teaching? Four studies were located which dealt with this problem. Three were doctoral dissertations. Jeffrey (1967b) studied student performance objectives for the chemistry laboratory. He classified these objectives into one of six areas of competence: (1) vocabulary, (2) observational, (3) investigative, (4) reporting, (5) manipulative, and (6) laboratory discipline. As a part of

his dissertation research, Jeffrey proposed tests for three of these six areas, with the tests consisting of slides and films of the laboratory and calling for written student responses.

Jensen (1973) was interested in establishing a list of acceptable terminal behavioral objectives for the non-major general biology laboratory. Jensen considered that such laboratories are taught by specialists not really in tune with the students who take such courses. As a result, the non-science majors are turned off and never take another laboratory science course. Jensen limited the participants in his study to instructors in Missouri institutions of education who teach a general biology laboratory course for non-majors.

Jensen prepared a questionnaire containing 85 terminal behavioral objectives and asked respondents to react to each using a five-point Likert-type scale of importance. From the responses received (50%), Jensen identified 29 objectives that would be acceptable to a majority of the instructors.

Lee (1978) surveyed the literature to identify objectives of laboratory work in biology and located 120 functions. Using these functions she developed two instruments to measure perceptions about the role of the laboratory. She worked with science educators, college biology teachers, teaching associates, and college students.

Lee reported that the participants in her study accepted the five major functions of the laboratory identified in the literature: manipulative skills; processes of science; knowledge of subject matter, nature of science; and attitudes, interests, and values. Different groups rated these functions differently in terms of importance. Students enrolled in the course for science majors, even if they were non-majors, considered manipulative skills more important than did their peers who were enrolled in a science course designed for non-majors. [This finding would seem to coincide with Pickering's (1980) misconception number two: laboratories exist to teach "finger skills."]

Pella (1961) identified objectives by analyzing high school textbooks and laboratory workbooks and by reviewing curriculum outlines of courses of study.

However, if we operate on the assumption that what actually goes on in classrooms and laboratories is more important than the goals people say they espouse, it seems logical to look for research in which teaching practices are observed and reported.

Research on the Realities of the Science Laboratory

Much research on teacher behavior in science classrooms has been reviewed elsewhere (Balzer et al., 1973) and will not be re-reviewed here. Included in this section of the paper are recent observational studies, completed since the teacher behavior review was published, as well as survey studies related to teaching conditions and practices in science.

Observational studies. Egelston's study (1973) probably deserves a mention here although it follows the pattern of the interaction process analysis studies reported in the teacher behavior review. Egelston developed a cell physiology and nutrition unit designed to promote the discovery method of science teaching and investigated to see what changes in teaching method and resultant behavior, learning, and climate were produced. Observers trained in the use of a modified Flanders system (17 categories rather than Flanders 10) gathered data in the experimental and traditional classrooms. Students were also asked to respond to the Learning Environment Inventory (LEI) near the end of the unit. Egelston reported that, when the two student groups were equated for entering behavior, the control group surpassed the experimental, but that the reverse situation was true at the end of the unit. The two groups also differed in perceptions of the socioemotional climate of the classrooms.

Egelston found the control group to score significantly higher on intimacy, satisfaction, and diversity while the experimental group was characterized by apathy, formality, goal direction, and disorganization. (A reverse Hawthorne effect?) She concluded,

> . . .The validity of the LEI appears questionable in the light of such results. . . .When verbal behavior coding was analyzed, the experimental group used significantly more indirect behavior but displayed only slightly less direct behavior than the control . . .the amount of direct behavior was overwhelmingly large compared to the small amount of indirect behavior in both groups. . . (pp. 473-474).

Egelston did report that students in the experimental group were decidedly more independent but the reader does not know if "decidedly" indicates a level of significance--therefore, it probably does not.

Further discussion of Walberg's Learning Environment Inventory is found in a paper by Rentoul and Fraser (1978). These authors consider the LEI inappropriate for use in inquiry classrooms, contending that it was developed for use in conventional classrooms and with senior high school students. Rentoul and Fraser have developed the Individualized Classroom Environment Questionnaire (ICEQ) based on Moos' work, which has been reported more in the psychological literature than in education.

Their ICEQ instrument has five scales (personalization, participation, independence, investigation, differentiation) related to three dimensions (relationship, personal development or goal orientation, system maintenance and system change). Rentoul and Fraser claim that the ICEQ gets at students' perceptions of the actual classroom learning environment and

perceptions of their preferred learning environment. There are 10 items in each scale. The ICEQ has been tested and can be understood by junior high school students. It can be administered in 20 minutes.

Fordham (1978) has also written about the influence of student perceptions on learning. It is Fordham's contention that such perceptions are influenced by the particular characteristics of the student. Student behavior (perceiving, remembering, or problem solving) is an outcome of the relationship between the student and his learning environment. Using the "needs-press" model of Murray, Fordham looked at achievement-oriented behavior, intrinsic motivation, and students' level of cognitive readiness (prior development of those cognitive structures necessary for learning a particular section of curriculum). Working with 17 fifth-form biology classes (274 students), Fordham concluded that it is necessary to examine the nature of the interaction between the student and his/her learning environment before testing for the presence of effects of student characteristics on perceptions of the classroom (p. 97).

Linn, Chen and Thier (no date) have reported on some work with middle school students in science. Influenced by Bruner, the investigators assumed that learning is most likely to take place when students are interested in what they are investigating and when the learning task is challenging but not frustrating. This can be facilitated by allowing students to pick their learning task as well as the apparatus to accomplish it. They also cite Piaget's work as indicating that most upper-elementary-age children are quite concrete in their logical thinking and thus are more likely to learn from concrete experiences than from abstract descriptions of experiences.

Linn et al. worked with two fifth grade classes in an upper middle class school. Pupils worked on science activities twice a week for nine weeks, forty-five minutes at a time. Staff observed that the students' use of apparatus was primarily exploratory. A concrete approach was used and variables were investigated unsystematically. The pupils appeared unable to think ahead, to plan experiments, or to design controlled investigations under conditions of the apparatus but with no specific directions. They were not able to suggest activities without the help of a knowledgeable adult and were influenced by their peers in choices of activities and procedures.

The researchers concluded that the social structure of the classroom and the fact that most rewards in the usual classroom come from the teacher influenced the behavior of these fifth grade students. They suggested that pupils unaccustomed to working independently find the transition from group to personalized work difficult. Such pupils may need to be provided with an introduction to independent work. Also, methods for rewarding independent work need to be established (p. 24).

Another investigator who also worked with intermediate grade students was Lancy (1976). He reported on a year-long project in an experimental school associated with the Learning Research and Development Center of the University of Pittsburgh. Lancy spent two hours a week in the school's science laboratory as a participant-observer. Lancy said that the science

laboratory was one of the favorite school settings for fourth and fifth grade pupils. Students had class there once a week for 45 minutes, by homeroom groups. They could also come there as a self-directed activity. When they did so, the pupils had to work on the science curriculum for 10 minutes and then were free to do what they wanted.

Lancy reported that these pupils, even in the homeroom groups, worked as individuals or pairs. Their activities ranged from reading to investigation. The teacher in charge of the laboratory reported that pupils gravitated to learning resources that involved manipulation of materials and avoided those requiring a great deal of initiative or any amount of reading (p. 9). Lancy characterized the science laboratory as having an atmosphere of movement and excitement not present in the other school settings.

Tamir, in an article entitled "How Are Laboratories Used?" (1977), investigated five problems: (1) differences in high school laboratory experiences at different grade levels, (2) the extent of inquiry orientation, (3) the characteristics of inquiry and non-inquiry teachers in the laboratory, (4) the characteristics of different college laboratories, and (5) how college and high school laboratories differed. Tamir modified Smith's earth science observation instrument for items related to pre-laboratory, laboratory, and post-laboratory. He looked at 18 high school biology teachers and their classes (grades 9, 10, 11) and four different laboratories in Hebrew University (first year chemistry and physiology, second year history, and physiology for medical school). Two different observers were involved in this study.

Tamir reported that, in grades 9 and 10, one-fourth of the time was spent in the pre-lab phase, two-thirds in the laboratory, and post-lab time was rather short. In grade 11, the pre-lab was short and the post-lab phase occupied one-third of the time. He did not find a post-lab phase in college laboratories and concluded that written reports substituted for this. In high school biology, 11% of the total lab time was devoted to verification and 13% to investigation (p. 313). To obtain what he called an "investigatory index," Tamir divided inquiry by investigation.

Tamir found that, in college laboratories, pre-lab time was positively related to the complexity of the task and negatively related to the availability of previously prepared guidelines. There was a low investigative index in the laboratory work for all four college laboratory courses (p. 313), indicating the need for a critical look at undergraduate science laboratories.

Other investigators also were interested in college science laboratory instruction. Shymansky and Penick (1979) reported the development of an instrument termed SLIC (Science Laboratory Interaction Categories) devised specifically for use in science laboratories. This instrument contains teacher categories and student categories. Behaviors are coded every three-to-five seconds. Use of SLIC tells an individual (1) the specific nature of the behavior being exhibited, (2) to whom a specific behavior is being directed, and (3) the sex of the student or teacher to whom the behaviors are being directed.

Shymansky and Penick wrote, "The primary goal of the laboratory experience for the beginning science student should be to reinforce through concrete example and direct manipulation of materials the same basic concepts presented as an abstraction in the lecture or text. . ." (p. 195) while Tamir wrote about verification laboratories and inquiring laboratories.

According to Tamir, in the verification laboratory the teacher identifies the problem to be investigated, relates the investigation to previous work, conducts demonstrations, and gives direct instructions. Students repeat the teacher's instructions or may read aloud the instructions from the laboratory manual. In the inquiring laboratory, the teacher asks the students to formulate the problems, relate the investigation to previous work, and state the purposes for the investigation. The students do all these tasks, as well as performing the investigation (p. 311). It would appear that the Shymansky and Penick instrument has been designed primarily for use in what Tamir calls verification laboratories.

Kyle et al. (1979) reported a study in which the Science Laboratory Interaction Categories (SLIC) instrument was used to investigate and analyze specific student behaviors in introductory and advanced-level college science laboratories (botany, chemistry, geology, physics, zoology) at the University of Iowa. The researchers were interested in determining what the students actually do and if behaviors differed among the sciences. Using the SLIC in 10-minute observations in a laboratory, 333 student observations were made.

Kyle and his colleagues found (1) students spent only one-third of the available time experimenting (21.9% in introductory laboratories, 43% in advanced science course laboratories), (2) the behavior of asking questions rarely occurred (2% for both introductory and advanced courses), and (3) significant differences were found in the amount of time students spent listening to the instructor or to other students in introductory and advanced-level classes within science disciplines as well as among disciplines. The researchers concluded ". . . even at the college level students are performing cookbook-like laboratories and students are not learning the process skills of science but are learning about science. . ." (p. 549).

Fuhrman et al. (1978) have produced an instrument called the Laboratory Structure and Task Analysis Inventory (LAI). It is designed to facilitate the analysis of laboratory investigations in secondary school science. Its use can produce a quantitative picture of the kinds of activities required of a student in performing laboratory investigations. Its authors report that the instrument was developed in response to the need for instruments designed specifically to test the quality of written laboratory manuals (p. 6).

The 1978 version of the Laboratory Structure and Task Analysis Inventory is a modification of an instrument developed by Tamir and Lunetta for use with biological science materials. Further work involved the use

of the LAI with physics curricula and, later, chemistry. Although the LAI has been primarily used with laboratory handbooks, its developers consider it of potential usefulness with a wider range of curriculum materials.

Lunetta and Tamir (1978) used the LAI to examine laboratory activities from Project Physics and the Physical Science Study Committee (PSSC) materials, to check on Herron's contention that the science course improvement project materials did not always lend themselves to the goals the project developers advocated. They decided that the laboratory guides for the two courses were still lacking in instructions and questions that might stimulate such inquiry activities as the formulation of hypotheses, the definition of problems, and the design of experiments.

They identified what they considered to be six important deficiencies where student involvement, or its lack, was concerned: (1) no student involvement in identifying and formulating problems or in formulating hypotheses, (2) relatively few opportunities to design observation and measurement procedures, (3) even fewer opportunities to design experiments and to work according to their own design, (4) lack of encouragement to discuss limitations and assumptions underlying the experiments, (5) lack of encouragement to share student efforts in laboratory activities when this is appropriate, and (6) lack of explicit provisions for post-laboratory discussions to facilitate consolidation of findings and understanding (p.10).

Another type of observational analysis was described by Platts (1976). He reported the use of super-8 movie film to record activity during single and double laboratory periods. Three schools, six teachers, and five laboratories were involved in his study. Platts looked at movement and classified it as teacher-centered or pupil-centered. He suggested that using this filmed system is a way to see what physical activity takes place in the laboratory and to identify what portions of the lab room are most frequently used.

Survey studies. An earlier small-scale survey by Anderson (1949) was reported in another section of this review. A more recent one, involving biology teachers, was reported by Beisenherz and Olstad (1980). They developed a questionnaire identifying 26 laboratory activities that might be done in high school biology. Items for the questionnaire were derived from an analysis of some of the more widely used high school biology programs. They surveyed teachers in the New Orleans and Seattle metropolitan areas and asked them to tell if they used the laboratory activity. If they did not, the teachers were asked to indicate, from a list of eight reasons, why the laboratory activity was not performed. Beisenherz and Olstad reported that lack of materials and equipment and a low priority of the laboratory topic were the most frequent reasons given for not doing an activity. They found that the Seattle teachers used more laboratory activities than did the New Orleans teachers.

When the factors limiting biology instruction were considered, the five most important factors were (1) lack of materials and equipment, (2) large number of students per class, (3) lack of facilities (tables, storage, gas, electricity, etc.), (4) lack of time during the school year

to achieve course goals and to utilize laboratories, and (5) lack of teacher preparation time.

Two larger-scale studies of science education practices in the United States are those produced by the Research Triangle Institute in North Carolina, under the direction of Dr. Iris Weiss (1978), and a case studies project operating under the direction of personnel at the University of Illinois (Stake et al., 1978a,b). The national survey and the case studies were both funded by the National Science Foundation in an effort to assess the status of science education, mathematics education, and social science education in the United States.

The national survey was designed to collect information to be used in answering 11 questions. Questionnaires were mailed to superintendents, supervisors, principals, and teachers, with samples being selected using a multistage stratified cluster design. The 11 questions were:

(1) What science courses are currently offered in schools?

(2) What local and state guidelines exist for the specification of minimal science experiences for students?

(3) What texts, laboratory manuals, curriculum kits, modules, etc. are being used in science classrooms?

(4) What share of the market is held by specific textbooks at the various grade levels and subject areas?

(5) What regional patterns of curriculum usage are evident? What patterns exist with respect to urban, suburban, rural, and other geographic variables?

(6) What "hands-on" materials, such as laboratory or activity-centered materials, are being used? What is the extent, frequency, and nature of their use by grade level and subject area?

(7) What audio-visual materials (films, filmstrips/loops, models) are used? What is the extent and frequency of their use by grade level and subject area?

(8) By grade level, how much time (in comparison to other subjects) is spent on teaching science?

(9) What is the role of the science teacher in working with students? How has this role changed in the past 15 years? What commonalities exist in the teaching style/strategies/practices of science teachers throughout the United States?

(10) What are the roles of science supervisory specialists at the local district and state levels? How are they selected? What are their qualifications?

(11) How have science teachers throughout the United States been influenced in their use of materials by federally funded in-service training efforts in science?

Questions 3, 6, 7, 8, and 9 are particularly relevant to this review of the role of the laboratory in science teaching.

Science course improvement projects for elementary school students have emphasized a hands-on approach for science teaching, with students actively involved in the manipulation of materials rather than reading science textbooks. Before a teacher can use or order curriculum materials for use, he/she must be aware that the materials exist. The national survey questionnaire contained a listing of 34 different science curricula, with 12 of these titles being for elementary school science.

Twenty-seven percent of the K-6 teachers reported they had not seen any of the science materials. In grades K-3, 29% of the teachers were using some of the elementary science materials, as were 31% of the teachers in grades 4-6. The three projects frequently reported in use were the Science Curriculum Improvement Study (SCIS), Science-A Process Approach (SAPA), and the Elementary Science Study (ESS), in that order. Secondary teachers were significantly more likely to be using federally funded science curricula than were elementary teachers.

Fifty percent of the biology teachers were using at least one of the Biological Science Curriculum Study (BSCS) materials, 40% of the physics teachers were using Harvard Project Physics (HPP) or the Physical Sciences Study Curriculum (PSSC) materials, and 25% of the chemistry teachers were using either the Chemical Bond Approach (CBA) or Chemical Education Materials Study (CHEM Study) materials.

Teachers were asked to identify instructional techniques from a list of 16 as to frequency of use: never, less than once a month, at least once a month, at least once a week, or just about daily. The techniques were:

lecture,
discussion,
student reports or projects,
library work,
students working at chalkboard,
individual assignments,
students use hands-on manipulative or laboratory materials,
televised instruction,
programmed instruction,
computer-assisted instruction,
tests or quizzes,
contracts,
simulations (role-play, debates, panels),
field trips/excursions,
guest speakers, and
teacher demonstrations.

Techniques used almost daily in K-3 science instruction were discussion (39% response), lecture (18%), and student projects or reports

(9%). Thirty percent of the K-3 teachers reported using laboratory materials at least once a week. Teachers of grades 4-6 reported almost daily use of discussion (58%), lecture (23%), and individual assignments (13%). Twenty-five percent of the 4-6 teachers reported using laboratory materials at least once a week.

Films were used at least once a week by 17% of the K-3 teachers for science lessons and at least once a week by 14% of the 4-6 grade teachers. These two teacher groups reported that they also used filmstrips at least once a week: 12% of the K-3 teachers and 14% of the grade 4-6 teachers.

At the secondary level, two-thirds of the science classes used lectures at least once a week, with 25% of the teachers indicating the lecture method was used daily. (Lectures were never used in 16% of the science classes.)

Laboratory work was done once a week in at least 48% of the science classes, although 9% of the science teachers indicated that laboratory work was never done. Discussion was used by 85% of the teachers once a week or more, and student reports or projects were used at least once a week by 20% of the secondary school science teachers.

Given a list of 18 problems or factors affecting science instruction, science teachers identified as the four most important factors: (1) lack of materials for individualizing instruction, (2) insufficient funds for purchasing equipment and supplies, (3) inadequate facilities, and (4) inadequate student reading abilities.

In relation to the questions the Research Triangle survey was designed to answer, the investigators found, among the following results, that (1) the most extensive use of federally funded science curriculum materials was in grades 7-12 and (2) the textbook still retained a central role in science teaching, with lectures and discussions being the predominant teaching techniques, although 48% of the science classes used hands-on materials at least once a week with this use increasing with grade level.

Under the direction of Robert Stake at the University of Illinois, a case study research project was completed which involved 11 high schools and their feeder schools. The sites were selected to provide information from a variety of areas: rural and urban; east, west, north, and south; racially diverse; economically varied; innovative and traditional; and areas where new schools were being built and those where schools were closing. Field researchers acted as educational anthropologists, living in the communities from 4-15 weeks and interacting with teachers, students, and parents. Their findings, while they encompass more of science education than the role of the laboratory, have implications for this review.

While the locations differed in important ways and each teacher made unique contributions, there were some generalizations that could be made from the case studies. Nationally, science education was being given low priority, yielding to increasing emphasis on basic skills (reading and

computation). Science faculties worked hard to protect science courses for the college-bound. These courses were often kept small by prerequisites and "tough" grading. Only occasional efforts were made to do more than read about science in the elementary schools. Ninth grade biology and general science courses flourished, although general education aims for science instruction were not considered vital at any grade level. Seldom was science taught as scientific inquiry. Science, as well as mathematics and social studies, was presented as what experts had found to be true. School people and parents were supportive of what was being chosen to be taught, although they complained occasionally that it was not taught well enough. The textbook was seen as the authority on knowledge and guide to learning. The teacher was the authority on social and academic decorum. Teachers worked hard to prepare their pupils for tests, subsequent instruction, and the value-orientations of adult life. Although they were relatively free to depart from the district syllabus or the community's expectations, teachers seldom exercised either freedom.

In discussing the findings related to science education, in the summary of the case studies, the authors used the phrase which the NSTA report has publicized: The teacher is the key. They said, "What science education will be for any one child for any one year is most dependent on what the child's teacher believes, knows, and does--and doesn't believe, doesn't know, and doesn't do. For essentially all of the science learned in school, the teacher is the enabler, the inspiration, and the constraint."(Stake & Easley, p. 19:1, 1978c). Some children learn science out of school but most do not. "For most, systematic science learning will occur only if the teacher can cope with the obstacles and is motivated to teach something of the knowlege and inquiry of the scientific disciplines"(Stake & Easley, p. 19:2, 1978c).

Decisions as to changing the science curriculum were largely in the hands of the teachers. While teachers could not always bring about the changes a few would have liked, they regularly could stop the curriculum changes they opposed, either at the district level or in the classroom. They were largely alone in a personal struggle to select and adapt available materials to educate a distressingly reticent student body. The role teachers play in setting the purpose and quality of the science program was apparent in all case studies and reaffirmed in the national overview.

As the student body grows smaller, the faculty grows older. Old solutions seldom fit new problems. Most teachers have trouble teaching at least a few children. Teachers needed assistance of one kind or another. In most of the case study sites the in-service program was providing little aid, partly because it was anemic and aimed elsewhere, partly because the teachers paid little heed to it; the in-service personnel seen were seldom oriented to helping teachers solve such difficult problems as keeping the lesson going or adapting subject matter to objectives for which it was not originally prepared. The teachers were apparently sometimes more on their own than they wanted to be.

In school settings, greater emphasis was given to reading and arithmetic and to the results of minimum competency testing aimed at the

basics; less emphasis was being given to science, math, and social science concepts and relationships. Teachers were willing to take this trade-off, saying that youngsters would not understand complex ideas until they could read them. . . . Teachers appeared to be fully convinced that improvement in all of education, including science education, was directly dependent on improvement in reading. (Stake & Easley, p. 19:2-3, 1978c).

With perhaps an exception or two, in the case of environmental education, there were essentially no interdisciplinary efforts in the case study schools. Most high school science departments were offering biology for all students and either chemistry or physics or both for the students going on to college. These latter two courses usually had an algebra prerequisite, which helped keep the course geared for the "faster" students. Laboratory work in several sites appeared to be diminishing in importance because of the expense, vandalism and other control problems, and the emphasis on course outcomes that would show up on tests. A general science course was a standard offering in junior high schools almost everywhere.

Although there were a few elementary teachers with strong interest in and understanding of science, the number was insufficient to suggest that even half of the nation's youngsters would have a single elementary school year in which their teacher would give science a substantial share of the curriculum and do a good job of teaching it (Stake & Easley, p. 19:3, 1978c).

The science curriculum of the schools was, in operation more than by definition, taken to be a set of knowledges and skills rooted in the academic disciplines. It was to be shared in common by all students who would undertake the study of science. Though it may emphasize conviction in one place and skepticism in another, it was to be seen as belonging to the collective wisdom of men, a part of the culture, a property that exists outside the individual learner.

The curriculum was not the arrangement of context and contracts so that students would have optimum opportunity to extend their own meanings of things--to learn those things that interested, challenged, or puzzled them. It was course-and skill-centered, authoritarian, external; the motivation to learn was expected to be external (Stake & Easley, p. 19:4, 1978c).

The predominant method of teaching science was recitation, particularly in the junior high school. (Assign, recite, test, discuss.) The high school class was more likely to use some workbook exercises, possibly in groups at lab tables, but the emphasis was still on recitation, with the teacher in control, adding new information and sometimes demonstrating. The textbook was the key to information.

Textbooks and other learning materials were not used to support learning and teaching; they were the instruments of teaching and learning. Learning was a matter of developing skills, of acquiring information, and the guide and source was the textbook. Most of the time the science teacher asked students to tell what was in the reading assignment. Reading time during the period was common. Homework was not very common.

When people were interviewed about priorities in education, a large number said other things were more important than science. They did not wish to diminish the science program nor did they express a strong desire to have science programs upgraded. Seventy-five percent of the superintendents, science teachers, and parents said the lower priority for science education would have a serious effect on the growth of technology in our society, the economy in years ahead, and the quality of life in this country. More than 80% said the schools should do something to reverse this trend.

The researchers found very little anti-science feeling. While people wanted a strong science program, they thought reading, vocational skills, writing ability, and remedial courses needed attention first (Stake et al., 1978b, p. 8).

The most common perception of the function of science education was preparation for later training, for college, for work, or for increased understanding of the environment. (Stake & Easley, 19:13, 1978c).

Barriers to improving science education at the local level were identified. The one largest barrier seen by all groups was student behavior, particularly student motivation. Financial barriers were often mentioned. Teachers indicated dissatisfaction with materials that did not conform to their responsibilities for socializing youngsters. Many students found courses boring (Stake & Easley, 19:16, 1978c).

Schools were not intellectually stimulating places. There was a "love it or leave it" attitude about much of education in 1977. "Teacher support systems" were weak and needed vitalization. A teacher having difficulty carrying out ordinary science teaching was seen to be without sufficient aid, though many agencies exist for the purpose of providing aid. Teachers said their resource people largely did not know the realities of their classroom situations. There was substantial need for pedagogical support for teachers. Many of the good ideas had not caught on.

The case studies resulted in the identification of some strengths, some problems, and some non-problems. Among the strengths were (1) the large responsibility given to the individual teachers to decide what will be taught and how it will be taught, (2) the respect shown faculties of science and math by the general public, (3) the sincere regard teachers have for the well-being of students, (4) NSF institutes for in-service training, (5) the intuitive understanding of knowledge youngsters have, (6) the vast array of resources for learning science that are available, and (7) a mellowing of faculty attitude toward science and technology.

Problems include (1) diminishing school funding for instruction, (2) diminished concern for scientific ideas, (3) poor pedagogical support for teachers, (4) insufficient support for opportunities to learn science out of school, (5) emphasis in the school program on preparation rather than utilization, and (6) schools no longer providing a spokesman for science.

The case study researchers also identified some factors they termed "non-problems," defining these as those problems getting a more substantial

amount of attention than was justified in the opinion of the researchers. These include (1) differences in perception of the objectives of the schools (diversity was considered to be a good point), (2) the quality of reading and other basic performances of students was too low (the case study group suggested that the schools need to educate people, not impose minimum standards), (3) lack of articulation (this may not be needed), (4) little interdisciplinary efforts (perhaps it is too difficult to teach in an interdisciplinary manner), (5) level of work in the schools was highly dependent on competition with an overemphasis on grades, and (6) diminishing respect for authority (it is healthy for people to be questioning rather than submissive).

If science does not rank as a high priority in the school curriculum, if the emphasis is on recitation rather than on experimentation, if schools are not intellectually stimulating places, and if laboratory work is deemphasized because of expense, vandalism, and other control problems, plus the emphasis on course outcomes that show up on tests, the case study data serve to illustrate a bleak prospect for investigative laboratory science.

Added to this is the philosophical view of science as belonging to the collective wisdom of men, a property that exists outside the individual learner, a point of view which tends to promote the use of the laboratory as a dispenser of knowledge rather than a place where knowledge is discovered, as Pella (1961) contrasted the situations.

A third large-scale survey was reported in "Science Education in Nineteen Countries, International Studies in Evaluation I" by Comber and Keeves (1973). This study involved 20 countries although Israel did not test in science (hence, the 19 in the title). Fifteen countries tested all three student populations: 10-year-olds, 14-year-olds, and 18-year-olds. This study was a first attempt

> (1) to devise cross-national measures of achievement in science, measures based on a systematic analysis of the curricula in participating countries; (2) to apply those measures to probability samples of students for different countries and to derive acceptably accurate national profiles of achievement; and (3) to determine how these profiles relate to school, home, and national circumstances. (p. 299)

It was reported that home background was a good predictor of student achievement but that its contribution varied considerably from country to country. Measurement of learning conditions within the school accounted for enough variation in achievement to support the idea that schools do have an impact on the learning of science. In terms of sex differences, boys generally did better than girls in science, with the gap being widest among the older students. Boys also showed more interest in science. The authors remark that, for those persons believing that girls are not given fair treatment in science, IEA findings "provide dramatic evidence of the scope of the problem" (p. 299).

In the beginning section of this review, when historical developments and their effects on science education were discussed, one of the factors mentioned was the increase in enrollment in the public schools. IEA researchers were interested in looking at the effects of admitting a larger proportion of an age group to secondary school. They viewed their data as indicating that the best students do as well or nearly as well in the less selective school systems as in those that are more selective. (Perhaps it is possible to teach science for the citizen as well as for the scientist and not handicap the scientist.) In fact, the less selective systems are reported to show less social bias in terms of father's occupation and end up with more students studying advanced science courses (p. 300).

The authors also report, ". . . Another important finding is the fact that, where used, practical tests were shown to measure abilities that were rather different from those measured by standard tests" (p. 300).

Related to this information about the laboratory were other findings stated at various points in the study report. For example, in six countries where students (10-year-olds) reported they made observations and did experiments in their school, the school's level of achievement in science was higher than where students did not perform these activities. This evidence would appear to provide clear support for the use of observation and experimental work in teaching science to children of this age group (p. 212).

In four countries (of 13) where students responded positively to the question, "We usually make up our own problems and design our own experiments," they performed less well on tests. This might suggest that unstructured learning in science does not lead to as high a level of achievement as does more structured learning (p. 212). Such a finding appears in contradiction to the emphasis in the federally funded science curriculum improvement projects in the United States and the central idea in many of these materials that experience in planning investigations should play an important role in the learning of science. However, the tests used in the IEA study did not assess the ability to plan science investigations so this dilemma cannot be resolved.

Relative to the 14-year-old group, the most important factor for a knowledge and understanding of science, after home background and type of school and program were taken into account, was the extent to which students had the opportunity to study science. Exposure to science appeared to influence level of achievement (p. 236).

As mentioned earlier, an attempt was made to assess students' laboratory or manipulative skills in science--their practical abilities, as the authors name them. Optional tests of practical abilities requiring only very simple and easily obtainable materials were produced. However, only two countries elected to use these practical tests. Even with this limited sample, the point was reinforced that such tests measure quite different abilities from those assessed by more traditional tests, even those tests designed to assess practical skills as far as possible without resort to actual apparatus. If students' first-hand experience is to

become an essential feature of school science, then the further development of such practical tests is highly desirable - if not imperative (p. 288).

Comber and Keeves admit,

> It is disappointing that no clear light is thrown on the problems uppermost in the minds of many Science curriculum workers and teachers, namely the roles to be played by practical work and by inquiry methods. What evidence there is seems to suggest that in the early stages controlled practical work achieves better results than more informal investigation, and that later in the Science program freer methods of inquiry do not necessarily bring beneficial results (p. 296).

It would appear that the problem with which this review is concerned (the role of the laboratory and finding support for it) goes beyond national boundaries. It also seems evident even an international study does not produce definitive results. A few individuals have ventured to suggest that the problem really does not lend itself to research. More counter with the argument that the research methodology, not the problem, is where the blame should be placed. This next section of the review will contain information related to this topic.

SOME ADDITIONAL REMARKS ABOUT RESEARCH ON LABORATORY INSTRUCTION

Research Design and Reporting

Many of the readers of this review will be familiar with the 13 criticisms of science education research which Curtis stated in the second volume of his "Digests" (1971b) and which were repeated by Jacobson (1974) in his paper entitled "Forty Years of Research in Science Education." For those few who are not familiar, the criticisms were (1) failing to state the problem definitely; (2) assuming the equivalence of experimental groups without taking adequate steps to ensure this equivalence; (3) securing equivalence of groups upon a basis other than that in terms of which results are measured; (4) failing to isolate the experimental factor; (5) delimiting too rigorously the teaching methods under investigation; (6) assuming the definitions of teaching methods under investigation to be standard (i.e, commonly accepted); (7) failing to report the technique in sufficient detail; (8) mingling findings and conclusions with details of methods; (9) evaluating on the basis of only one criterion, when that criterion is but a single element in a more complex process or situation; (10) employing crude subjective tests in measuring results; (11) making gross errors in recording data; (12) including personal opinions among the findings and introducing personal bias into the investigation; and (13) making sweeping generalizations from obviously insufficient data (Jacobson, 1974, pp. 7-8).

Cunningham (1946) reviewed 25 years (1912-1943) of research on the problem of laboratory work vs. lecture-demonstration. He reported that he considered 13 general questions in selecting and analyzing the studies. (1) Were the experimenters, and agencies to which the research work on this problem was submitted, reliable? Yes; (2) Have the problems of these studies been definitely and precisely stated at the beginning of each undertaking? Not all were; (3) Have the separate specific problems or outcomes of the various studies been definitely stated at the beginning of each report? For the most part, but--; (4) Were variables, that should have been held constant, allowed in the experimental situation? Often; (5) Were variables, that should have been held constant, permitted in the methods of teaching used? Usually no; (6) What kind of data were obtained in these studies and how were they obtained? Generally, through the use of written tests; (7) Were the data obtained under a variety of conditions? The amount of information about this varies, but, probably, yes; (8) Were the data used in these studies valid? Usually there is evidence to support this; (9) Were the tests used in these studies reliable? Data are lacking; (10) How were the data handled? Statistical methods varied; (11) What results did the experimenters report? These also varied, but included retention (immediate or delayed), student interest, economy of time, laboratory resourcefulness, manipulative skills, etc.; (12) Have the experimenters been reasonably moderate in their claims concerning their findings? For the most part; and (13) How have the studies, as wholes, been ranked by the critics? Results varied--for example, 7 were considered very good, 11 as intermediate, and 6 as inferior.

Kruglak and Wall (1959), who were interested in developing laboratory performance tests to be used in general physics classes at colleges and universities, also reviewed laboratory instruction research. In their review, they used five questions as guides: (1) Did the investigator make a sufficiently detailed report of his work so that it can be properly appraised? (2) Did the investigator use the best contemporary experimental procedures and techniques? (3) Were the research data subjected to the best analytical treatment known at the time of the study? (4) Has the investigator been reasonably cautious in interpreting the data and drawing conclusions? and (5) Did the investigation make a contribution to the field?

Kruglak and Wall suggested that research needs to be carried out relative to (1) the formulation of general and specific objectives of laboratory instruction, (2) the relationship between the laboratory and other areas of instruction, (3) the development and validation of tests in harmony with stated instructional objectives, and (4) experimentation and rigorous evaluation of novel laboratory instructional methods. They identified some specific questions that might be considered: How useful are laboratory performance tests as predictors of achievement in advanced laboratory courses? in research laboratories? Which laboratory experiences are better taught by the individual method and which by demonstrations? (p. 161).

The remarks of McKeachie (1963) concerning the difficulty of conducting research on two different methods of instruction have been discussed earlier in this review. Writing in the same publication, Watson (ed. Gage, 1963) contributed a chapter on research on teaching science. A sub-section of Watson's chapter (pp. 1041-1044) was focused on laboratory work. In it he discussed 16 studies and concluded that the whole area was still open for investigation. Watson said that the hypotheses studied should come from a careful analysis of the important operations of science which can be illustrated and practiced in the laboratory. Watson identified some variables that might be considered in this research: sex, career aspirations, general IQ, prior laboratory experience, manual dexterity, and ability in solving problems in spatial relations. He suggested that researchers need to look at the nature of the task, the motivation of the student, and behavior patterns of the teacher in defining the task and motivating students.

Boud, Dunn, and Kennedy (1980) published a short article in the Journal of Chemical Education, reporting that they based their article on an appraisal of more than 250 reports on laboratory teaching of chemistry, physics, and biology appearing in the literature between 1970-1977. They identified three trends: (1) individualization of laboratory work, in the form of self-teaching packages and individualized computer-assisted learning techniques, occurring in the early stages of undergraduate teaching; (2) project work and participation in research is receiving increased emphasis, with more emphasis on community-oriented and team-based projects; and (3) breaking down of administrative barriers between lectures, tutorials, and laboratory classes, also with some integration of subdisciplines.

These authors pointed out that the reports they reviewed varied in detail included. They identified six areas which should be included in reports about laboratory teaching, and suggested that information should be included about:

(1) The aims of adopting the methods:
   a) to solve specific problems associated with space, staff, apparatus.
   b) to change the attitudes of students, to increase relevance of the course, to make the subject more enjoyable.
   c) to investigate the efficacy of particular approaches in the context of course goals of curriculum constraints.
   d) the relationship of these aims with the objectives of the particular course.
(2) The context in which the innovation was applied:
   a) the numbers of students involved and the nature of the particular course.
   b) the "normal" approach adopted to the teaching of the particular segment.
(3) The methods by which student performance was assessed:
   a) particularly as they relate to the stated aims of introducing the innovation.
   b) an indication of the results of assessing student performance if possible comparing these with a control group or historical summary of previous performance patterns.
   c) the results of pre- and post-tests or other assessment procedures.
(4) The approach adopted:
   a) including special features such as peer group assessment and special relevance to the work situation.
   b) description of particular equipment, arrangement of laboratory, space, facilities for staff interaction.
   c) number of staff, both academic and technical, required to support the program.
   d) summary details of the experiments including any special features of the materials or learning aids.
(5) The evaluation procedures used to measure the impact of the approach:
   a) an account of student attitudes and perceptions of the approach and their opinions as to how the style of teaching has operated.
   b) an account of opinions of the staff involved as to the success or otherwise of the technique.
   c) an estimate of comparative costs of the new technique compared with the more "usual" approach to the teaching. This comparison should make some reference not only to equipment and materials but also to the level of academic and support staffing required.
(6) Similar approaches reported elsewhere by other authors:
   a) highlighting areas of similar and contrary experiences.
   b) emphasizing any modifications to standard models of innovation which have resulted in improvements. (1980, pp. 456-457)

This additional detail will be of use to persons interested in curriculum development as well as to those interested in research.

Stuit and Engelhart wrote "A Critical Summary of the Research on the Lecture-Demonstration Versus the Individual-Laboratory Method of Teaching High School Chemistry" which was published in Science Education in October, 1932. In their article the authors spent some time in identifying the factors to be considered when setting up controlled experiments in education: specification of instructional procedures in detail, equivalent groups of pupils (IQ, study habits, chronological age, previous achievement in such subjects as physics, general science, mathematics, participation in extra-curricular activities, home environment, sex, race, physical condition), control of teacher factors (zeal, personality, preference for method to be used), school size, administration and supervision, school organization, school building, community attitude and interest as well as same sequence of topics, same time of day, time devoted to learning activity. They also stressed that researchers should not let students know they are in an experimental situation. They suggested that the experimental treatment should last at least a semester or preferably a school year. They advocated the use of equivalent forms of an achievement test in chemistry of known and high reliability for the initial and final testing. They also suggested that researchers test for such outcomes as laboratory techniques and manipulative skills, abiding interest in chemistry, and scientific attitude. If possible, there should be a later retest to measure retention.

Stuit and Engelhart (1932) then proceeded to identify and discuss various experimental studies in light of (some of) the criteria they imposed. They ended by citing conclusions favoring the use of the laboratory; conclusions favoring the demonstration method; conclusions of no significant difference, and general, overall conclusions. They reported (1) no method is considered best in every case; (2) in small schools where money and space are not plentiful, the lecture-demonstration method seems most practicable; (3) written tests cannot test all outcomes of high school chemistry and tests of a manipulative variety for evaluating laboratory skills are needed; and (4) "The problem of the relative merits of the lecture-demonstration and individual-laboratory methods still seems unsolved and as complex as ever. . ." (p. 391).

R. C. Bradley, Earp, and Sullivan (1966) wrote "A Review of Fifty Years of Science Teaching and its Implications," published in Science Education. They reviewed elementary school science from 1920 to the present (presumably, 1965) in 10-year periods and highlighted what was taught for each decade.

In discussing elementary school science they wrote

> The purpose of the elementary science program is to provide the opportunity for students to learn the processes or methods as well as the content of Science. . . The science program should lead students to scientific self-activity and to think as scientists think; i.e., to identify problems, gather facts relevant to the solution of problems. . . A most significant form of learning comes from the process of carrying forth an idea in experimentation and making adjustments so that experiment is successful. . . (p. 153).

They advocated a developmental approach in teaching elementary school science--simple concepts to complex, from concrete objects to abstract ideas.

In 1968, in Science Education, R. L. Bradley published an article entitled "Is the Science Laboratory Necessary for General Education Science Courses?" He provided some historical background on the development of laboratory instruction in college science and reviewed previous research in this area. Using 10 questions modified from the 13 Cunningham (1946) reported using, Bradley examined studies related to what he termed general education science.

In the conclusions section of his article, Bradley wrote

> Although most of the data seem valid, the diversity of findings appear to cast some doubt on the validity of the tests, the adequacy of the controls of such factors as instructor conditions, and the use of small unrepresentative groups and no retrial of experiments. There also seems to be no standard lecture-demonstration or laboratory method . . . . (p. 65).

Like Stuit and Engelhart, writing 36 years earlier, Bradley grouped his conclusions into those in favor of the laboratory method, those in favor of the lecture-demonstration, and those of no significant difference. His general overall conclusions also parallel those of Stuit and Engelhart, as follows:

Bradley, 1968:
> No one method can be considered superior in all cases. The objectives of science teaching, the ability level of the students, and the facilities available should largely determine the method used.

Stuit and Engelhart, 1932:
> No method can be considered to be the best in every case. The objectives of chemistry teaching, the preference of the teacher, the nature of the pupil, and the facilities of the school will largely determine which method should be used.

Bradley, 1968:
> Where costs per student is a major concern, the lecture-demonstration method seems to offer the best advantages.

Stuit and Engelhart, 1932:
> In small schools where money and space are not plentiful the lecture-demonstration method seems to be most practicable.

Bradley, 1968:
> The problem of the lecture-demonstration method versus some kind of laboratory method still seems unsolved and as complex as ever. It appears that there should be more careful experimentation involving careful control of non-experimental factors. More reliable testing is needed before any definitive answers can be given. When experimentation has indicated that a particular

Bradley, 1968(cont'd):

> method is superior in outcomes, the method must still be examined in terms of the values of these outcomes relative to the costs involved.

Stuit and Engelhart, 1932:

> The problem of the relative merits of the lecture-demonstration and individual-laboratory methods still seems unsolved and as complex as ever. More careful experimentation, involving careful control of non-experimental factors and reliable testing, is needed in order to justify any definite and final conclusion. When experimentation has shown the relative superiorities of the methods in terms of outcomes, the methods should be evaluated in terms of the values attached to these outcomes. (Bradley, p. 66; Stuit and Engelhart, pp. 390-391)

"The more things change, the more they remain the same" appears to be an appropriate, even if trite, remark at this point.

If there are any generalizations to be drawn from this small section of the review, these appear to be that caution needs to be exercised in the selection and application of research methodology, more detail needs to be provided in the reporting of research, and thus far, definite and final conclusions have yet to be found and communicated.

If At First You Don't Succeed

Nevertheless, researchers persist. The assumption that the laboratory can, or does, must make a difference is so deeply ingrained in most of us that we continue to investigate even when we are not heartened by the results we find. Although it is not an article in which shortcomings of research methodology or research reporting are discussed, a report by S. C. Brown (1958) is included here because it serves to illustrate this point. Brown, in an article published in the American Journal of Physics, reported several studies (or one study with several sub-parts) done at the Massachusetts Institute of Technology (MIT).

Personnel at MIT wanted to build on high school physics courses in their MIT science program. They sent a questionnaire to high schools and preparatory schools sending students to MIT to ask about their secondary school physics programs and got 1311 responses. MIT personnel looked for correlations with the laboratory grades of students who had had previous (equivalent) experiments in secondary school. Nine hundred MIT freshmen students were involved in this investigation. Six MIT physics experiments were found to be equivalent to those in secondary schools, with 300-400 students having had these experiments. There were no statistically significant differences in the laboratory grades of the two groups: those with equivalent experiments vs. those without.

So, another study was undertaken -- to see if people recognized laboratory apparatus. Students were asked to name a piece of apparatus, to tell what physical quantity it measured, and to provide a brief description of how the experiment (using the apparatus) was performed. The researchers

analyzed the data from the 700 students involved in this study and found they could have settled for only the first question. Only 41% of the students recognized they had studied the experiment using the apparatus.

Next the MIT researchers looked at 329 students who had had physics as seniors in high school and 318 who had taken the course as juniors, to see if they differed in recognition of apparatus. They found the recognition rate to be 41% for those taking physics as seniors and 40%, for those taking it as juniors. They also tested 84 students who had not taken a laboratory course in physics. Their recognition rate was 30%, so there seemed to be some advantage to having had a laboratory course in physics in high school.

It was decided to try the recognition test with MIT sophomores who had completed the physics experiments during their freshman year. Their average recognition score was 38%! Brown concluded,". . .knowledge about specific experiments is not retained either at the high school or the university level. . ." so ". . .design of experiments should be geared to overall educational value rather than for specific training in details of apparatus or experiments" (p. 336).

When graduates of preparatory schools were tested, their score was 48%, statistically significant over the other freshmen, but still showing less than a 50% retention rate. The MIT researchers looked at the two groups (public vs. prep school graduates) on the basis of their CEEB scores: those ranking in the 500 range and those in the 700 range. They also looked at students within the two groups who had not done similar experiments and the grades they made. No significant differences were found relative to any of these situations.

From the questionnaire data the MIT researchers had learned that 120 of the 1311 responding schools did not use commercial laboratory manuals for physics. They then looked at the students who had graduated from these schools, thinking that the teachers who would spend time and effort to write their own laboratory manual must have made some impact on their students. No significant differences were found for this group as compared to other students on their MIT physics grades. ". . . only one correlation showed a significant trend. . ." in that, on strange and unusual experiments, students from the teacher-produced-laboratory-manual-classes earned, on the average, a five percent higher grade than equivalent students who had used commercial manuals (p. 336).

The freshman class was interviewed at the end of the year by the MIT laboratory staff to see what they considered to be of educational value in their high school physics laboratory, now that they had had a year of college work. Nothing specific was identified. However, the majority of the freshmen thought that ". . . without an enthusiastic introduction to physical sciences in their secondary school education, they would not have chosen science or engineering as a profession. . ." (p. 336).

Brown therefore concluded that the intellectual stimulation and scientific challenge of laboratory education at the secondary school level is the most important single function of science. Laboratory education at

the university level must have as its goal the teaching of the scientific point of view and the intellectual challenge of the experimental method rather than the training of students in particular or specific techniques or in carrying out particular experiments.

This point of view seems to relate closely to that expressed by Welch (1976) when discussing declining test scores in science. Welch identified five possible explanations for declining scores and then speculated that the test score decline might be due to an increase in the affective outcomes of schooling. Using data, from 350 science classes, from student scores on two affective measures (Science Attitude Inventory and Learning Environmental Inventory-Satisfaction), Welch reported statistically significant gains on measures of class satisfaction and science attitude. He suggested that while students may be learning less science (as indicated by achievement test scores), they are enjoying it more.

Perhaps we need to pay more attention to the affective aspects of using the laboratory in science teaching. However, researchers have investigated attitudes as a dependent variable when the laboratory was used, with no significant differences studies predominating. In addition there is the problem, discussed earlier, of attitude toward science vs. scientific attitudes.

The Science Laboratory and Disadvantaged Students

As the enrollment of the schools has increased, subgroups of the school-age population have become centers of concern. In prior decades the Americanization of immigrants was a focus of educators. Now one of the concerns is for the education of disadvantaged students. Baillie's report (no date) mentioned earlier in this review is based on the premise that discovery activities in science with active student participation will promote interest in school and school work. However, he does not cite any research support.

Bredderman (1979), in a paper presented at a meeting of the American Educational Research Association, reported preliminary findings of a meta-analysis of elementary school science process curriculum studies. He said that disadvantaged students using process programs gained more intellectually than did control groups. When process groups were compared with other groups using some combination of laboratory work with a textbook, the advantage of the process outcomes was reduced almost to zero -- implying that the active involvement of the process approach or some other laboratory approach was the critical factor.

Two researchers worked with populations of older disadvantaged students. McKinnon (1976) reported a six-week summer program designed to help pre-engineering freshmen learn to think logically. Forty-three students were involved: 41 Blacks, 1 Chinese-American, 1 Chicano; with 5 of the 43 students being female. Pre-tests provided data showing that 28 of the 43 students were concrete operational in their thinking and 7 were at the formal operational level. (Apparently the others were in some transitional stage.)

The students were placed in a logic of science laboratory in which they were faced with situations they could not resolve with the understanding they presently had. Students were pre- and post-tested to determine the effects of their laboratory experience. In the laboratory they went through activities related to the conservation of volume, equilibrium in the balance, separation of variables, exclusion of potential variables, and elimination of contradictions (tasks described by Inhelder and Piaget). Eleven of the students moved from concrete to formal level. Twenty-eight of the 43 students exhibited positive growth in thinking (this was not elaborated in the article), while four decreased in this ability (p. 741).

McKinnon said that the students needed to interact with materials normally provided in a well-structured laboratory course. Their previous educational experiences had been mostly passive activities with little opportunity for critical thinking. In the logic of science laboratory they were provided with an abundance of opportunities for interacting with materials and for verbalizing with other students and teachers. Such experiences resulted in a significant increase in the ability to think logically. McKinnon also reported that he had talked with the students pre-testing at the formal operations level and found that, for these students, with ". . . more extensive laboratory-oriented science courses, classroom interaction was better remembered, and more warmth toward these activities was exhibited. Where students had taken a course in which the lecture approach was used very extensively, their feelings toward both subject and teacher were generally negative" (p. 743).

McKinnon considered that his findings had implications for engineering schools. These institutions need to re-orient their physics and chemistry classes in order to modify a straight lecture approach. There is need for longer periods for assimilation of information. Perhaps individualized or self-paced approaches are needed. Teachers need to be skilled in perceptive questioning. Laboratory activities should be designed to create disequilibration.

He emphasized that minority students need more time, benefitting from a self-pacing approach to instruction, as well as longer time for taking tests. They also need to have a greater emphasis placed upon step-by-step problem analysis and to have the same opportunities to interact with materials, the teacher, and other students as their advantaged peers have. McKinnon also suggested that high schools could improve the preparation of minority students for engineering education by appropriate career guidance, as well as by realistic grading.

McDermott, Piternick, and Rosenquist (1980) have reported on a project at the University of Washington designed to increase the number of minority students qualifying for admission to health science programs. They contend that minorities are under-represented in science-related professions as a result of being academically disadvantaged in high school. Therefore, minorities cannot succeed in college courses required for science-related careers. The University of Washington program involves a three-quarter sequence in physics and one quarter of biology.

In the discussion of crucial instructional strategies, the authors describe the role of the laboratory. Standard laboratory equipment and simple materials are used to give students direct experiences which will serve as the basis for generalization and proper formation of scientific concepts. Concepts are named after students have completed the laboratory activity.

McDermott et al., wrote that

> Importance of a laboratory setting for instruction can hardly be overemphasized. . . . for students whose reasoning skills are not yet fully developed, this is where scientific ideas should be introduced. The availability of concrete examples and the opportunity to manipulate the systems under study allow the students to gain experience on which to build the abstractions of science. . . . Moreover, the laboratory makes it possible for the students to relate representations such as graphs, diagrams, and verbal statements to the real world. Activities in the laboratory can also provide a focus for discussions among students, and between students and instructional staff (p. 202).

These reports, combined with several reviewed earlier, provide evidence that experiences in which students manipulate materials can serve to enhance cognitive development in terms of reasoning skills.

Assessing the Contributions of the Laboratory

The literature reviewed in this subsection deals primarily with the assessment of psychomotor skills. Kruglak and other authors were mentioned earlier as emphasizing the point that manipulative skills are more properly assessed by some means other than paper and pencil tests. Kruglak (1955, 1960) was particularly concerned with measuring the laboratory achievement of physics students. In an article published in 1955, Kruglak discussed a study in which three versions of a laboratory skills test were used: essay, multiple choice, and performance. He reported a low correlation between the performance test and the paper and pencil tests. Kruglak considered that this fact indicated that the paper and pencil tests were, at best, only crude approximations of evaluation of the ability to deal with laboratory materials and apparatus (p. 86).

In 1960 Kruglak submitted a report to the National Science Foundation describing the results of a project that NSF had funded. Kruglak had produced a book dealing with laboratory performance tests in college physics. This 165 page book was mailed to 1046 colleges and universities in the United States at which a general course in physics was offered. Copies (140) were also sent to science journals, apparatus makers, and colleges not identified as being on the American Institute of Physics list. Kruglak also sent out a questionnaire asking for informantion on current teaching practices in physics laboratories. He reported receiving replies from more than 500 colleges and expressed the desire to carry out a similar study five years in the future. Kruglak said that it was most surprising to find in many college science departments a most unscientific approach to science teaching. He recommended that the National Science Foundation fund research in science teaching, particularly at the college level.

Robinson (1969) published an article about evaluating laboratory work in high school biology. He said that, despite the emphasis on laboratory activities in the NSF-funded science course improvement projects, assessment of curriculum effectiveness remained at the paper and pencil level. However, he reported that teachers in one trial center for BSCS Blue Version materials had designed some new questions for a laboratory practical examination. They found four kinds of activities common to student work in the BSCS Blue Version: performing various kinds of measurements; naming or categorizing organisms, models, or apparatus; interpreting experiments; and seeing appropriate interrelationships of phenomena and ideas. These four kinds of activities were used as a framework for a 20-item laboratory practical examination. After some pilot work, the categories were revised into measuring, identifying, selecting, and computing (p. 236). These categories were discussed and the items each contains were described. The theme of the article appeared to be that laboratory exercises designed to teach science as inquiry are different from the old illustrative exercises. Therefore, new items should be designed to assess whether or not students have comprehended the nature, or structure, of scientific knowledge.

Another practical examination in biology was reported by Tamir and Glassman (1971). Their article contains some reference to an earlier practical examination with three parts: plant identification with a key, an oral examination on animals and plants, and a problem to be solved by an experiment. The current version contains four added problems dealing with DNA replication in Euplotes, osmotic behavior and permeability in plant cells, the relationship of respiration to temperature in fish, and the effect of enzyme concentration on the rate of starch hydrolysis. When results of the practical examination were correlated with achievement in paper and pencil matriculation tests and yearly school grade, the results indicated that the practical examination as a whole, as well as parts, apparently measured some aspects of achievement hardly measured by the teacher's grade or by paper and pencil tests (p. 308).

Tamir and Glassman discussed the criteria used for assessment: manipulation, self-reliance, observation, investigation, communication, and reasoning. The first two were assessed during the examination and the others derived from the answers students gave. Then they decided to see if this inquiry-oriented laboratory test would discriminate between BSCS and non-BSCS students: 60 12th grade students who had studied biology for four years and 142 BSCS students. They found the BSCS students performed significantly better than the non-BSCS students did, due mainly to the superiority of the BSCS students in reasoning and self-reliance. Tamir and Glassman concluded that BSCS students possess a distinct advantage in solving open-ended problems using experimental procedures in the laboratory (p. 314).

Venkatachelam and Rudolph (1974) reported on a laboratory examination for college chemistry which consisted of three parts: (1) two videotaped experiments in which typical mistakes had been deliberately made (students had to spot these mistakes); (2) simple laboratory tasks in which skill, accuracy, and speed were evaluated; and (3) multiple choice questions on a variety of topics (e.g.) simple laboratory calculations, chemistry theory behind some of the techniques used, inferences that could logically be drawn from a set of experimental observations.

Eglen and Kempa (1974) were also interested in evaluating students' laboratory performance in chemistry. They were concerned not with developing a practical examination but with assessment instruments. They reported on an experiment in which three types of assessment instruments were used with videotapes of students performing chemistry experiments. The instruments were open-ended, intermediate, and checklist in form. The most variability was found in the use of an open-ended instrument.

Klopfer (1971), in the "Handbook on Formative and Summative Evaluation of Student Learning," (Bloom et al., eds.), has prepared a table of specifications for science education (table 18-1) which contains columns headed "manual skills" and is divided into development of skills in using common laboratory equipment and the performance of common laboratory techniques with care and safety. Related to these columns are B.0, processes of scientific inquiry--observing and measuring; G.0, manual skills, related to manual skills involved in science laboratory work in the schools (p. 576).

Mitchell (1978) has written an article showing the use of an evaluation format, based on Klopfer's chapter, for evaluating inquiry in curriculum materials. Major headings in his scheme are processes of scientific inquiry -- (1) observing and measuring; (2) seeing a problem and seeking to solve it; (3) interpreting data and formulating generalizations; and (4) building, testing, and revising a theoretical model. Mitchell suggested that Klopfer's scheme may expect too much of curriculum materials by spreading the building, testing, and revising of a theoretical model over too many (six) categories. Mitchell considered it possible to condense these categories to four or even three.

Hofstein and Giddings (1980), in a technical report prepared for the University of Iowa, have provided examples of paper and pencil tests which could be used to evaluate laboratory skills.

Little and deM Maclay (1978) have developed a manual of basic skills in physics. They are concerned with the identification of laboratory and workshop skills relevant to the teaching of high school physics. They say that teachers do not have a lot of physics knowledge, although there is a lot of equipment available (thanks to government money) in Australia. Teachers need to be trained to use and maintain this equipment. Their manual of basic skills contains objectives for a psychomotor skills test for physics teachers. There are 10 objectives, each of which has a cognitive component as well as a psychomotor component.

Lunetta and Tamir (1979) emphasized that science teachers have moved, or should move, away from laboratory activities that emphasize illustration, demonstration or verification to those emphasizing hypothesizing, predicting, etc., as well as developing attitudes and skills consistent with the work of scientists and the understanding of scientific relationships, concepts, and models. They presented a checklist of 24 skills and behaviors they have culled from the literature and have related to the processes of scientific inquiry and problem-solving. These behaviors are grouped as relating to planning and design, performance, analysis, and application. The authors illustrated how this checklist may

be used with a laboratory activity by using it on a laboratory activity from Harvard Project Physics and one from the Yellow Version of the BSCS materials. A three-category marking system is used: + if the student behavior is called for at least once in the activity, - if it is never called for, and 0 if it is not possible to determine this. The physics and biology activities are then discussed in terms of what the use of the checklist can tell a secondary school science teacher about the activities.

Doran (1978) wrote that the question of how the laboratory can best be used is still not answered for instructional programs. He suggested that if educators want to use the laboratory to demonstrate how science operates, they need to decide on the behavior to be encouraged and then to design objectives and activities to achieve these ends. However, the precise relationship of student laboratory activities to the goals of school science courses is not clearly understood. Doran considered the lack of a conceptual framework for evaluation of science laboratory activities one of the greatest deficiencies in the measurement of science laboratory skills.

Doran posed the question: What skills are necessary for functioning in a science classroom laboratory setting? and proceeded to consider this in relation to work by Nedelsky, Klopfer, Robinson, Thomas, Eglen and Kempa, and Jeffrey. The information from Klopfer, Robinson, and Jeffrey has been discussed at other points in this review and will not be repeated here. Nedelsky has identified four stages underlying laboratory/performance tests: (1) laboratory knowledge, (2) understanding of the processes of measurement, (3) intuitive understanding of phenomena, and (4) ability to learn from experiments or observations.

Thomas has identified nine behaviors students follow in a laboratory assignment: (1) understand and follow instructions, (2) formulate method, (3) organize work and work space, (4) manipulate equipment and collect data, (5) record results accurately, (6) present results, (7) use of statistical methods, (8) discuss results and suggest follow-up work, and (9) survey the literature.

Eglen and Kempa identified four components of science laboratory activities: (1) methodical procedure, (2) experimental techniques, (3) manual dexterity, and (4) orderliness.

Based on this material, Doran concluded that cognitive, affective, and psychomotor elements are present in the necessary skills. He said that the development relative to the cognitive and affective domains has been greater than that in the psychomotor domain. However, the three domains overlap and interlock, with student behaviors being a combination of elements from all the three domains. Doran spent some time in a discussion of the use of checklists or rating scales vs. laboratory practical examinations, pointing out that the National Assessment of Educational Progress (NAEP) has given limited attention to manipulative exercises in its science test battery.

Doran concluded

> The relative stress on manual skills development in science programs is still a moot question. Each science teacher will differ in

> the emphasis he gives to the students' equipment manipulation and laboratory techniques. Research into psychomotor aspects of science laboratory objectives is woefully lacking. There are presently no universally accepted criteria for describing a student's science laboratory skills. . . (p. 407).

If Doran's review has been thorough and comprehensive and his view (that the question of how the laboratory can be used for instructional programs is still not answered) is a valid one, this is an area in which more science education research needs to be done.

SUGGESTIONS FOR FUTURE RESEARCH

Some Concerns from Current Literature

In addition to the areas of investigating the role of the laboratory in cognitive development or in overcoming deficiencies in logical reasoning in minority disadvantaged students, there are other possible research concerns.

Hofstein and Lunetta (1980), in a paper prepared to accompany a symposium on the role of the laboratory in science teaching (presented at the 1980 annual meeting of the National Association for Research in Science Teaching), have identified numerous areas. They consider that research should be done on specific conditions, methods, and strategies of laboratory work and their effect on learning outcomes. They suggest that dependent and independent variables should be more carefully monitored than in past studies. Variables to be monitored include (1) teacher behavior, (2) student behavior, (3) content of laboratory manual and laboratory activities, (4) classroom environment, (5) student characteristics and abilities, (6) student attitudes toward a variety of relevant issues, (7) student manipulative abilities, (8) student conceptual understanding, (9) student inquiry skills, and (10) laboratory management variables (i.e.,) time allotted to laboratory work, availability of laboratory space and resources, and method of grouping students (pp. 28-29).

Hofstein and Lunetta advocated that "promising variables neglected in past studies" should be investigated--the development of problem-solving and logical skills, and positive attitudes toward science and toward the student's perception of his ability to understand and to change his environment.

Hofstein and Lunetta maintained that, at present, there are insufficient data from well-designed studies from which to make unequivocal statements on the role and effectiveness of laboratory work in science teaching (p. 28).

Some Concerns from the Studies Reviewed

Certainly, because achievement and the emphasis on accountability are pressures with which science teachers must deal, there is a need to design achievement tests which more closely approximate the cognitive outcomes science laboratories of the investigative type can produce. It would be desirable to be able to teach science without having to worry about grades and grading but as long as grades are a primary method of communicating to parents and the general public how students are, or are not, progressing, we need to do more than cope with the situation.

Attitude studies were another type that received much attention in the science education research literature. This area also produced a large number of no significant differences results. We need to clarify what we mean when we talk about attitudes--are we hoping to promote positive feelings about studying science or are we attempting to produce students who think scientifically? If the second objective is the one we choose,

then we need to carefully delineate the behaviors by which we will determine whether or not scientific thinking is taking place. Then we will need to identify or develop instruments to test for this.

The "cognitive abilities" cluster contained a diversity of studies grouped together because some aspect of learning and cognition was investigated. Critical thinking and cognitive style are certainly different types of factors. As various reviewers have stated, we are in need of adequate, descriptive information as well as operational definitions for the factors we investigate and report about.

The area of interests was not investigated in many research studies identified for this review. This was, to some degree, surprising because many science teachers, in conversation, express the belief that involvement in laboratory activities creates student interest in studying science. Perhaps the small number of studies is symptomatic of the ebb and flow of interest in research topics. Possibly, people are assuming that if students hold positive attitudes toward science, interest will develop. Perhaps pressures to convince the general public that science is a "basic" have overshadowed the interest-promoting types of objectives for laboratory science.

Whatever we examine--recent research or that reviewed in the Curtis "Digests" -- we have to concur with Hofstein and Lunetta that we have insufficient evidence upon which to make unequivocal statements about the role and effectiveness of laboratory work in science teaching. The final section of this review will be devoted to the consideration of possible factors contributing to this situation.

SOME CONCLUSIONS AND SPECULATIONS ABOUT RESEARCH RELATED TO THE ROLE OF THE SCIENCE LABORATORY

The figure shown on page 109 is this reviewer's attempt to depict the factors that appear to be involved, directly or indirectly, in investigations into the role of the laboratory in science teaching. As McKeachie (1963) has said, it would appear to be a simple thing to compare one instructional method with another but it really is not.

Reasons for Teaching Science

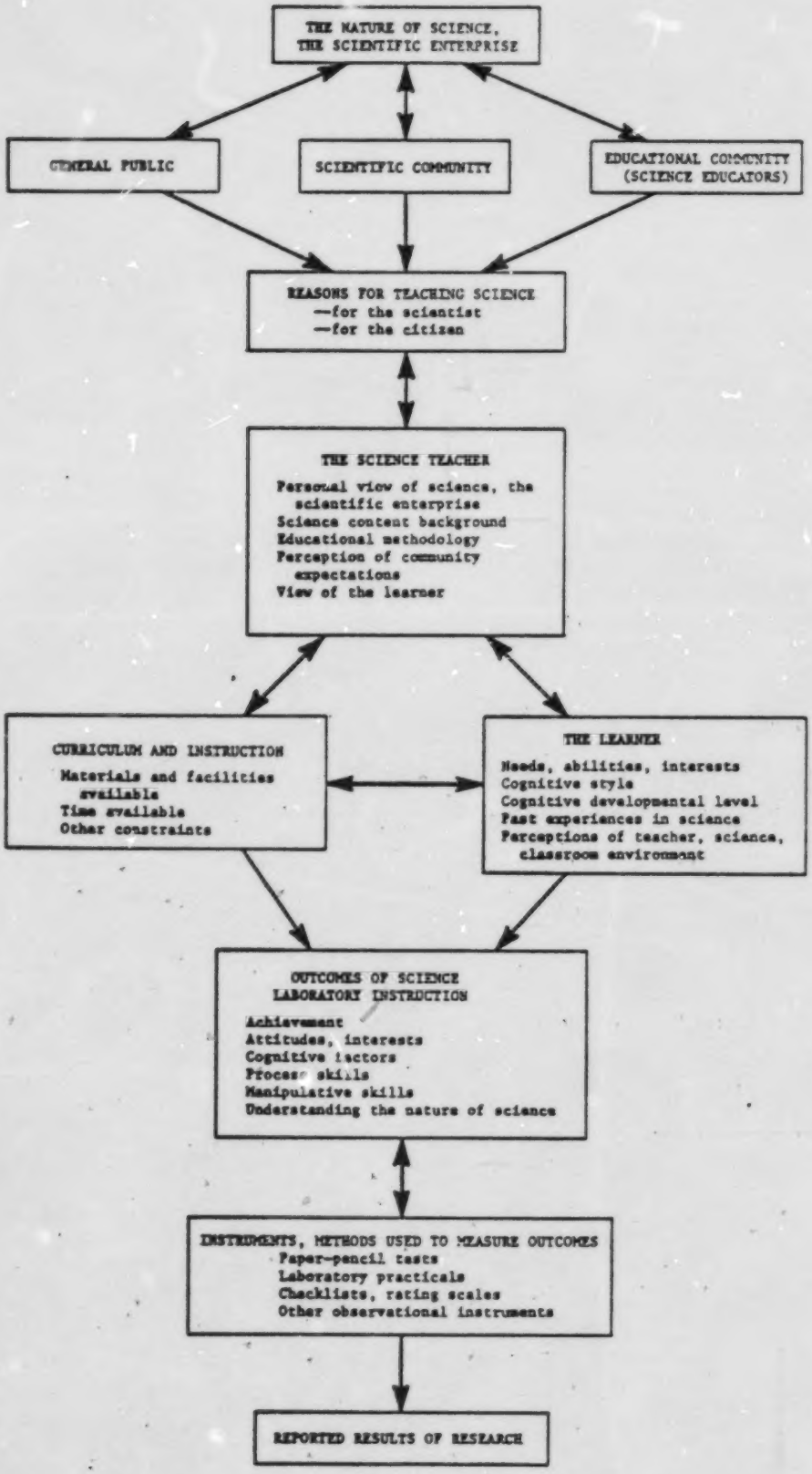
One of the reasons for teaching science is influenced by one's view of the purposes of education which were briefly discussed earlier in this review: to transmit the culture, to transform the culture, to promote individual development, or to combine some elements of all of these into an eclectic view. This philosophical bias serves as a filter through which information about the nature of the scientific enterprise is transmitted. In addition, the view of what constitutes the nature of science and the scientific enterprise appears to change over the years, with this view being influenced by ways in which the general public reacts to science as well as by the contributions of the scientific community to pure and applied science.

The educational community is also involved because of pre-service and in-service teacher education programs and activities. In addition, science educators and scientists are involved in the writing of textbooks and curriculum materials to be used in science classes. Individuals such as C. P. Snow, Jacob Bronowski, and others have done much to communicate about science to the non-scientist. Programs such as Bronowski's "The Ascent of Man" and, more recently, "The Search for Solutions," "The Body in Question," "Cosmos," and "Hard Choices" have been shown on public television during prime viewing hours.

Nevertheless, we have not apparently resolved what the aims of science teaching should be in terms of the population of the secondary schools. Hurd has written about teaching for the scientist vs. teaching for the citizen. Much has been written about the desirability of having a scientifically literate citizenry. Publications produced by the National Science Teachers Association (NSTA) and by the Educational Policies Commission of the National Education Association relate to this concern.

In Theory into Action (Hurd, 1964) the NSTA Curriculum Committee published the organization's position at that time on curriculum development in science. In their discussion of the nature of science, the committee characterized the scientific enterprise as having three aspects.

> . . .The first consists largely in observation and description of nature, and is sometimes called natural history. . . .The second aspect of the scientific enterprise, science, begins with the first--with observation, with descriptive statements, with simple, causal relationships derived from experiment. But it is important in science education to realize that the essence of science lies not so much in seeking out the detailed structure of nature as in trying to


THE NATURE OF SCIENCE, THE SCIENTIFIC ENTERPRISE
GENERAL PUBLIC
SCIENTIFIC COMMUNITY
EDUCATIONAL COMMUNITY (SCIENCE EDUCATORS)
REASONS FOR TEACHING SCIENCE
—for the scientist
—for the citizen
THE SCIENCE TEACHER
Personal view of science, the scientific enterprise
Science content background
Educational methodology
Perception of community expectations
View of the learner
CURRICULUM AND INSTRUCTION
Materials and facilities available
Time available
Other constraints
THE LEARNER
Needs, abilities, interests
Cognitive style
Cognitive developmental level
Past experiences in science
Perceptions of teacher, science, classroom environment
OUTCOMES OF SCIENCE LABORATORY INSTRUCTION
Achievement
Attitudes, interests
Cognitive factors
Process skills
Manipulative skills
Understanding the nature of science
INSTRUMENTS, METHODS USED TO MEASURE OUTCOMES
Paper-pencil tests
Laboratory practicals
Checklists, rating scales
Other observational instruments
REPORTED RESULTS OF RESEARCH

understand it. . . .As for the third aspect of the scientific enterprise, technology, the distinction between this activity and what we call science is probably more evident than that between natural history and science, where the boundary is not nearly as sharp. While science is an intellectual quest for understanding of natural phenomena, technology is a practical effort to use and control these phenomena. Technology yields the tangible products of science.

All three aspects of the scientific enterprise must be a part of the science curriculum:

1. descriptive science or natural history, because it provides the basis for scientific inquiry and plays so prominent a role in a child's conventional experience;
2. science proper, because of its intellectual challenge, which should be a primary goal of scientific education; and
3. technology, because it serves so well to illustrate the practical application of scientific principles and because of its impact on modern society (pp. 43-44).

The committee wrote that it was clearly impractical to include each of the three categories to the same degree at all educational levels but that students should understand the distinction among these activities.

In 1966, the Educational Policies Commission produced a small book entitled "Education and the Spirit of Science," in which seven values were identified as underlying science; i.e.,

the longing to know and understand,
questioning of all things,
search for data and their meaning,
demand for verification,
respect for logic,
consideration of premises, and
consideration of consequences.

Another curriculum committee of the National Science Teachers Association produced yet another position statement for the organization. This was entitled "School Science for the 70's"(1971). This group maintained that producing a scientifically literate person was congruent with the more general goals of education: learning how to learn, using rational processes, building competence in basic skills, developing intellectual and vocational competence, exploring values in new experiences, understanding concepts and generalizations, and learning to live harmoniously within the biosphere (p. 47). They also characterized the scientifically literate person as one who

1) uses science concepts, process skills, and values in making everyday decisions as he/she interacts with other people and with the environment;

2) understands that the generation of scientific knowledge depends upon the inquiry process and upon conceptual theories;
3) distinguishes between scientific evidence and personal opinion;
4) identifies the relationshiop between facts and theory;
5) recognizes the limitations as well as the usefulness of science and technology in advancing human welfare;
6) understands the interrelationships between science, technology, and other facets of society, including social and economic development;
7) recognizes the human origin of science and understands that scientific knowledge is tentative, subject to change as evidence accumulates;
8) has sufficient knowledge and experience so that he/she can appreciate the scientific work being carried out by others;
9) has a richer and more exciting view of the world as a result of his/her science education;
10) has adopted values similar to those that underlie science so that he/she can use and enjoy science for its intellectual stimulation, its elegance of explanation, and its excitement of inquiry; and
11) continues to inquire and increase his/her scientific knowledge throughout his/her life (pp. 47-48).

Science in the schools should also be taught so that students become aware of the social aspects of science; so that they (1) perceive the cultural conditions within which science thrives; (2) recognize the need to view the scientific enterprise within the broad perspectives of culture, society, and history; (3) expect that social and economic innovations may be necessary to improve man's condition; and (4) appreciate the universality of scientific endeavors (p. 48).

Bronowski has perhaps summed up all of these aims in a few sentences in The Common Sense of Science (1958). He wrote,

> There is no sense at all in which science can be called a mere description of facts. It is in no sense, as humanists sometimes pretend, a neutral record of what happens in an endless mechanical encyclopedia. . .science is not the blank record of facts, but the search for order within the facts. And the truth of science is not truth to fact, which can never be more than approximate, but the truth of laws which we see within the facts. . . . (p. 130)

It is this behavior or conceptual set that we hope to achieve in our science students, although we have not said it this directly in position papers or statements of goals and objectives. The use of the laboratory should contribute to such an outcome.

The Role of the Science Teacher

After the three large-scale National Science Foundation-funded studies were completed and published [the national survey (Weiss, 1978), the case

studies (Stake et al., 1978), and the literature review (Helgeson, et al., 1978)], numerous groups attempted to determine the common elements to be found in these studies. One publication that resulted from such a synthesis attempt was produced by the National Science Teachers Association and is entitled "The Teacher is the Key" (in What Are The Needs..., 1980). This title reflects this group's findings that what takes place in the science classroom is controlled, either directly or indirectly, by the teacher.

If this is a valid assumption, and it would appear to be, then the science teacher is an important variable influencing research studies on the role of the laboratory. Even if the research involves audio-tutorial instruction, such instruction is usually compared to a more traditional approach which is assumed to have both lecture and laboratory components. Even in the audio-tutorial mode of instruction, some individual has chosen the content to be emphasized and sequenced the instructional activities.

When we consider secondary school science, we need to recall the comments derived from the case studies: that what science education will be for a student is dependent on that the student's teacher believes, knows, and does--or doesn't believe, doesn't know, doesn't do. Therefore, when a researcher comes along and asks a teacher to teach in a certain fashion, problems may arise. If the teacher is not carefully prepared to use the experimental materials and methods or uses them but does not find their emphasis consistent with his/her personal philosophy of teaching, it is unlikely that the experimental treatment will be carried out in all its aspects as the researcher would wish.

The opposite effect may also occur. In fact this did, to some extent, take place with teachers using the federally funded science course improvement project materials. The Hawthorne effect, or the halo effect, of being part of a trial testing of materials developed by teams of scientists, teachers, and science educators generated a degree of enthusiasm among teachers.

Some research studies of the role of the laboratory did take into account some teacher variables but these were usually of the easily measured variety: age, sex, content background, years in teaching. What we need also consider is the teacher's understanding of the nature of science, his/her perceptions of desirable objectives for science teaching, and views of the ways in which science teaching should take place. Some research of all of these topics has taken place, as is evident from the classroom interaction studies involving the use of instruments such as the Biology Classroom Activity Checklist (BCAC) of Kochendorfer (1967) or the Biology Laboratory Activity Checklist (BLAC) of Barnes (1967), both developed as a part of research efforts to study the ways in which biology teachers used BSCS materials. Second-and-third generation efforts have produced the Science Classroom Activities Checklist (SCACL) of Sagness (1970) or the Checklist of Assessment of Science Teachers (CAST) of Brown (1972). A number of these instruments have two versions (teacher perceptions and student perceptions) of what is taking place in the classroom.

It might be profitable to look more carefully at teacher perceptions of science laboratory activities, as did Barnes, and compare this set of data with perceptions of the students.

Does the science teacher's content background make any difference in his/her view of science and, if we may extrapolate, science teaching? Herron (1971) interviewed science teachers participating in a summer science institute to get their perceptions of what scientific enquiry was. He reported

> . . .the biology teachers as a group have more of a tendency at least to talk about such abstractions as 'scientific method,' 'enquiry,' and 'open-ended' laboratory exercises. The physics teachers, as a group, show a decidedly greater orientation toward discussions restricted mainly to content. They showed much less concern for problems related to the teaching of the nature of the scientific enterprise. A slight positive correlation was noted between the amount of teaching experience and level of response. That is, the more recent college graduates in our sample showed a greater tendency toward 'content orientation' than individuals with more teaching experience. (p. 208)

How generalizable are the differences Herron identified in his sample? What implications do Herron's findings have for the way teachers present science in the laboratory and for the ways in which they interact with students? What influence do student perceptions have on outcomes of research on the role of the science laboratory?

The Learner in the Science Laboratory

Certainly the student has been the focus of more laboratory research than has the teacher. Results are reported in terms of student gain scores on some instrument or collection of instruments, or changes in student attitudes or interests or some other student variable. Perhaps most investigators have not pursued the question of student effects to the depth, or variety, that Brown (1958) reported in the research with physics course and MIT students, but certainly student outcomes have been the concern of laboratory research.

Classroom environment. In addition to the instruments named in the previous subsection of this paper that include measures of student perception of classroom activities, Parakh (1970, in Simon and Boyer, eds.) has developed an interaction system focused on the cognitive behaviors of individual pupils in biology classes. This system is based on the same theoretical foundation is Parakh's teacher-pupil interaction system, also for use in high school biology classes (in Balzer, Evans, Blosser, 1973). The categories in both systems deal with the cognitive aspects of teacher and pupil behaviors (with only a minor emphasis on non-verbal behaviors) and these are not unique to biology classes, e.g., teacher demonstrates, teacher gives laboratory and substantive directions, etc.

Tamir (1977) reported an investigation in which he used a modification of Smith's earth science observation system in chemistry, physiology, histology, and biology classes and laboratories. It would appear that science educators already have available instruments that might be used to measure verbal, and non-verbal, interaction in a laboratory setting. The problem appears to be more that of deciding on the appropriate instrument--a specific one such as Parakh's or Smith's or a more general one such as the Science Laboratory Interaction Categories system of Shymansky and Penick (1979). Researchers would be well advised to identify the theoretical basis for the instrument they are considering before putting it to use in order to make certain they are using a system which will collect the kind of data they wish to analyze.

In addition to the classroom interaction types of instruments, another instrument used in several studies to determine learners' perceptions of instruction (Egelston, 1973; Rentoul and Fraser, 1978) is the Learning Environment Inventory (LEI). This instrument was developed by Walberg and Anderson (1968) as a part of the research related to Harvard Project Physics. Some discussion of this research is contained in an ERIC/SMEAC Occasional Paper on Harvard Project Physics by Welch (1971b). Walberg and Anderson describe the instrument as consisting of 105 items designed to measure classroom climate in secondary schools. Students react to each item on a five-dimensional scale from "Strongly Agree" to "Strongly Disagree." The instrument's scales are Intimacy, Friction, Cliqueness, Apathy, Favoritism, Formality, Satisfaction, Speed, Difficulty, Goal Direction, Democratic, Disorganization, Diversity, and Environment.

Researchers associated with the University of Minnesota have reported data from administration of the Learning Environment Inventory (LEI). Welch, in a 1977 research paper, discussed a long-term study of the stability of learning environments. Using a stratified random sample of all secondary schools in 15 states in the western two-thirds of the United States, Welch and others obtained data designed to answer these questions: are educational environments constant over time? do perceptions of science and mathematics environments differ? and do perceptions of junior and senior high school students differ? The period of time involved the comparison of data from 1972 and from 1976.

One science or mathematics teacher was randomly selected per school and one class for each teacher was also randomly selected for response to the LEI. Welch reported 53% participation in 1972 and 45% in 1976, with approximately 50% repeaters. Data were obtained from 1121 classes, having approximately 22 students per class. A modification of the original LEI was used in this research. The modified LEI instrument contained 10 seven-item scales: Diversity, Formality, Friction, Goal Direction, Favoritism, Difficulty, Democratic, Cliqueness, Satisfaction, and Disorganization.

Statistically significant differences were found, suggesting the presence of duration, curricular, and age effects. On some of the LEI scales, junior and senior high changes were different for science and mathematics. On Formality, Friction, and Diversity the senior high school student scores were lower than were those for junior high school students.

Science and mathematics differences were greater for older students (1977, (p. 10), with the science mean being higher. Welch interpreted the results as showing that 1976 students perceived their classes as more organized, formal, goal directed, and satisfying than did the 1972 students. This shift to an environment that is a more orderly or structured learning climate, is, in Welch's opinion, a "more conservative" approach to science teaching (p. 11).

When science and mathematics class differences were considered, science classes were described, through the LEI, as being more diverse, disorganized, and formal, and possessing higher levels of friction, cliqueness, and favoritism than were mathematics classes. Mathematics classes were described as higher on goal direction, difficulty, and democracy. Science and mathematics classes rated equal on satisfaction (p. 12).

Welch considered that science classes with a substantial laboratory component will vary considerably in subject matter and provide many opportunities for social interaction. Therefore, it might be expected that students will perceive such classes as more diverse and disorganized with greater likelihood for cliqueness, friction, and favoritism to develop (pp. 12-13).

Senior high school students perceived their science classes as being more difficult, satisfying, and democratic than did junior high school students. Junior high school pupils saw their science classes as disorganized, diverse, and formal with higher levels of friction, cliqueness, and favoritism. Again, it is possible that junior high school science classes that are student-and activity-centered will exhibit less structure and greater social conflict and, therefore, be less satisfactory situations as pupils perceive them. Welch remarked that this situation seems to go with the age group (junior high) which he described as volatile. In 1976, as compared to 1972, junior high school students reported their science classes as more formal and less difficult.

What picture do the 1972-1976 comparisons reveal? There have been changes from 1972 to 1975, in a conservative direction. Science classes are perceived as being more formal, organized, and goal directed. Students are more satisfied. Science which is activity-oriented allows for strong student interaction with possible outcomes of cliqueness, friction, favoritism, and disorganization. Because such factors do not appear to be emphasized in the 1976 LEI results, science classes may be described as having a more traditional learning environment. Some of this change may have resulted from the emphasis on "the basics" or from the use of more conventional textbooks.

Welch has provided some questions that might be investigated and which involve the use of the LEI: why do students learn more in a classroom climate perceived as difficult? to what extent are friction and cliqueness deterrents to learning? how can we minimize the volatile climate of the junior high school? what climate characteristics of science classes are desired goals in and of themselves? and are there any LEI characteristics that could be used to explain declining science enrollments? (p. 18).

Rentoul and Fraser (1978) discuss the use of Walberg's Learning Environment Inventory (LEI) in science education research. They consider it less than appropriate for use in inquiry classrooms because, they write, it was developed for use in conventional classrooms and with senior high school students. They have developed the Individualized Classroom Environment Questionnaire (ICEQ) which has five scales: personalization, participation, independence, investigation, and differentiation. These are related to three dimensions: relationship, personal development or goal orientation, and system maintenance and system change.

The ICEQ instrument is designed to measure students' perceptions of the actual classroom learning environment and perceptions of their preferred learning environment, as well as teachers' perceptions of these aspects. Rentoul and Fraser report that the instrument can be understood by junior high school students and can be given in 20 minutes. Their paper was presented at a meeting of Australian researchers (1978) which would account for the lack of use of this instrument to date in the United States.

Grades. When the learner is being considered in research on the role of the laboratory, it is well to keep in mind McKeachie's remarks (1963) about determining which of two teaching methods is more effective. Much of the research on the role of the laboratory has involved groups of college students enrolled in beginning science courses or in science courses for non-majors. McKeachie makes the point that many college students are so grade-conscious that they will study on their own to make up for what they perceive to be deficiencies in instruction--when these perceived deficiencies may be a part of the research treatment. How universal a phenomenon is this concern for a respectable grade and how much influence does this concern have on the outcomes of a research study? Certainly it must be a factor in those investigations in which achievement is a dependent variable.

Cognitive style. How much influence does a student's cognitive style have relative to laboratory activities? Cognitive style, as opposed to critical thinking abilities or level of cognitive development, was investigated by Pringle and Morgan (1978) in a study designed to determine the influence of laboratory-oriented experiences in the Science Curriculum Improvement Study (SCIS) program on the stability of cognitive style (field-dependent vs. field-independent) of teachers. Although SCIS materials are designed for elementary school students, Pringle and Morgan worked with graduate students (in-service teachers) enrolled in a summer school program. The investigators termed their study exploratory in nature and reported that it implied that when a teacher's cognitive style was influenced significantly in the direction of field independence, the individual's ability to construct learning experiences for perceptual and intellectual tasks might also be enhanced (p. 50). Can this be translated into suggestions for use in the secondary school science laboratory?

While some individuals consider cognitive style to refer primarily to field dependence/field independence, others use cognitive style to mean learning style. Learning styles appear to be a current concern for some curriculum specialists and supervisors but little has been published about

the effects of learning styles in science education research. Dembo (1977) cites a publication by Dunn and Dunn to illustrate that learning style diagnosis includes (1) time (when is student most alert?), (2) schedule (related to attention span), (3) amount of sound (that can be tolerated), (4) type of sound (that produces a positive response), (5) type of work group, (6) amount of pressure, (7) type of pressure and motivation, (8) place (where student works best), (9) physical environment and conditions, (10) type of assignments, (11) perceptual strengths and styles (kinds of media and experiences), and (12) type of structure and evaluation (p. 54). Many of these elements relate to laboratory work and may merit investigation.

Past experiences in science. Many of the laboratory investigations reviewed for this publication involved college students who were enrolled in science courses of the general education/non-major variety. It seems logical that such students have had little previous experience with science or that their previous experiences did not prove sufficiently satisfying to cause them to consider science as a major in college.

Frequently students are placed in courses, or treatments for research studies, which are of the investigative variety in terms of laboratory activities and their past experiences have not equipped them to function effectively in such open-ended situations. Even science majors are sometimes frustrated by such situations. A dissertation announced in the July, 1980, issue of Dissertation Abstracts International relates to this situation. Manteuffel (1980) worked with a general biology course at the University of California at Berkeley. Students who enrolled in this course found themselves working in "investigative laboratories," a practice begun in 1969. Frequently students who completed the course were found to be both frustrated and lacking in basic inquiry skills. Manteuffel decided to develop guidelines which students could use to obtain basic information about formulating and carrying out a research problem. More than 300 students from Berkeley and from a community college and 50 instructors participated in Manteuffel's study.

Manteuffel reported that she found that most students had had no previous experience with independent investigations and that most did not know how to formulate a focused research problem or design a controlled and feasible investigation around a research problem. Many students were uncomfortable with lack of guidance and relied heavily on peers or instructors for ideas and answers. Students who used Manteuffel's guidelines were more positive about the investigations than were those who did not use these guidelines.

In the September, 1980, issue of Dissertation Abstracts International another study related to preparing students for laboratory work was reported. Hartford (1980) attempted to teach students enrolled in high school chemistry to ask questions in the context of laboratory experiments. Hartford considered improving the questioning skills of students as important as improving their teachers' questioning skills. He was also interested in determining if their level of cognitive development was a factor that needed to be considered relative to the development of questioning skills focused on problem-solving.

Students in the experimental treatment were exposed to unanticipated or discrepant events in a laboratory setting. The conceptual conflict such events produced could be reduced by students seeking further information through asking research questions, according to Hartford. The experimental treatment lasted 12 weeks and involved printed lessons designed to teach students to ask research questions in response to observations they did not anticipate in their regularly scheduled laboratory experiments.

Hartford reported that, by analyzing the post-test scores of unpretested students only, he found the experimental treatment effect to be statistically significant, accounting for 14% of the variance of the post-test scores. Level of intellectual development (measured by the paper-and-pencil Classroom Test of Formal Operations) had no effect on these post-test scores.

It is unwise to generalize from these two recent dissertation studies but they do identify some approaches which are of interest in investigating the role of the laboratory and ways in which the laboratory may be used more effectively to produce desired changes in students.

Effects beyond the laboratory. As McKeachie (1963) pointed out, little has been done to investigate the effects of the laboratory on students in terms of retention, in their ability to apply learning, or in the effects that having been enrolled in a laboratory course in science might have on students as they participate in other courses--either while taking the laboratory course or in subsequent years of college. Because most research is of the doctoral dissertation variety, the treatment is for a limited time and the effects of this treatment are observed and recorded over an even more limited amount of time.

Although several authors have contributed more than one research report focused on the laboratory, none of them has been involved in long-term research. The equivalent of an Eight-Year Study does not appear to yet exist in science education research.

The outcomes of laboratory instruction also need to be considered not only in relation to the classroom environment but also in relation to the teacher and pupils. The materials used, as well as the instructional techniques, also influence these outcomes.

Curriculum and Instruction in the Laboratory

Much has been written about the investigative/discovery laboratory as compared to the verification laboratory in science, for both secondary school and college students. The lengthy article by Herron (1971) illustrates the fact that even materials designed to be inquiry-oriented may be less open than their designers had intended.

In addition to the materials used, the methodology of instruction needs to be considered. As Tamir (1977) has pointed out, teachers differ in their use of pre- and post-laboratory activities and these differences can be used to differentiate inquiry and non-inquiry teachers in science laboratories.

Tamir (1976) has also provided some possible assistance to teachers who are concerned about building more student involvement into laboratory activities. This checklist (p.13) can be used to determine who (teacher, pupil) performs the following tasks related to the laboratory: (1) recognize and define problems; (2) formulate hypotheses; (3) predict; (4) design observation and measurement procedures; (5) design experiments; (6) carry out observations, measurements, and experiments; (7) record results; (8) transform results to standard format; (9) explain; (10) make inferences and draw conclusions; (11) formulate generalizations and models; and (12) define limitations.

The use of this list, combined with the model Herron (1971) proposed for determining the level of openness in laboratory activities, should enable a conscientious teacher to evaluate his/her approach to using the laboratory in science and to make changes, if needed.

To again quote McKeachie (1963, p. 1145): "Whether or not the laboratory is superior to the lecture-demonstration in developing understanding and problem-solving skills probably depends upon the extent to which the understanding of concepts and general problem-solving procedures are emphasized by the instructor in the laboratory situation."

In addition to considering both curriculum materials and instruction, the researcher also needs to recognize the limitations of the instruments used to obtain data.

The Outcomes of Science Laboratory Instruction and Their Measurement

No matter what the desired outcomes of laboratory instruction are--increased achievement, more favorable attitudes toward science, improved scientific attitudes, increase in level of cognitive development, increase in critical thinking skills, increase in science interest, improved manipulative or psychomotor skills, increased understanding of science and the scientific enterprise, or some other factor -- the appearance of these outcomes must be looked for and changes measured.

Outcomes of laboratory instruction in science have been measured with paper and pencil tests, with laboratory practicals, with the use of checklists and rating scales, with classroom observational instruments focusing on verbal or non-verbal interaction, or some combination of these. If the goals to be achieved are realistic, given the constraints within which the study must be done, the researcher needs to make certain that the measure used is sufficiently sensitive to detect significant changes that occur between the beginning and end of the treatment. Sometimes, there is no evidence that any teaching could affect the achievement of the goal as measured by the tests used (McKeachie, 1963, p. 1125).

In many studies investigator-designed tests or other instruments are used. Frequently information about reliability and validity, as well as the methods used to obtain these measures, is sketchy. An even more frequent lack is that of an explanation of the theoretical rationale underlying the instrument. These types of information are seldom found in

the abstract of a doctoral dissertation; frequently they are not provided in journal articles based on the dissertation research. Although there are space constraints for journal articles, knowledge of validity and reliability information is useful for readers who wish to make intelligent judgments concerning the data reported.

The effects of science laboratory experiences on achievement may be measured by the use of an investigator-designed test (pre-post, post-test only) or by the use of a well-known test such as the Nelson Biology Test, to cite only one example. There was not enough commonality the in area of achievement outcomes to permit generalizations other than those provided in an earlier section of this review. The same situation holds true for most of the other areas: attitudes, interests, cognitive factors, process skills, manipulative skills, and understanding the nature of science.

However, three instruments were used in enough studies so that small clusters were formed. These instruments were the Watson-Glaser Critical Thinking Appraisal, the Wisconsin Inventory of Science Processes(WISP), and the Test on Understanding Science(TOUS).

Watson-Glaser Critical Thinking Appraisal. According to information in the Mental Measurements Yearbook, edited by Oscar K. Buros (1959), the sub-tests of this instrument are designed to evaluate the ability to interpret data, to draw correct influences, to draw appropriate deductions, to recognize assumptions, and to evaluate arguments. Such mental operations can be accomplished in many content areas that are not unique to science. Is it possible then to develop these aspects of critical thinking without having students participate in laboratory activities? Test items involve written material related to problems and issues to which people react. Conducting a laboratory experiment may cause students to practice some of these activities (interpreting data, drawing correct inferences, etc.). But, if the experiment is of the verification type or if the student is working in a Level 0 or Level 1 situation (according to Herron's model)--even in inquiry-oriented materials--then there is little or no need for such mental activities to take place. The student just walks through the activity.

Twelve investigators used the Watson-Glaser test in their research related to the science laboratory. Two (Rogers, 1972; Sorensen, 1966) reported that students involved in their treatment groups made significant gains in their critical thinking scores. A third (Hoff, 1970) reported that the enquiry version group in a general education astronomy laboratory setting had the (significantly) highest adjusted mean score on the critical thinking test. Mandell's (1967) research provides a fourth report of gains in critical thinking scores. Mandell used college biology laboratory experiments specifically designed to develop or increase critical thinking abilities. He found that students having average or lower IQs showed a more significant gain in critical thinking after participating in the especially designed laboratory activities than did the students whose IQs were above the mean. (These students also exhibited more gain in biology achievement than did their peers with higher intelligence quotient scores.) Five (Dawson, 1975; Sherman, 1969; Stekel, 1969; Mitchell, 1978; Allison, 1973) reported no significant differences. Two (M. O. Smith, 1972; Edgar, 1969) reported results favoring the non-laboratory groups. The abstract of

Holloway's research (1976) contains the report of significant differences in critical thinking but does not indicate in whose favor.

Wisconsin Inventory of Science Processes. This test was developed by Wayne Welch as his dissertation project (no date). It is sometimes referred to as the Science Process Inventory (SPI) but the more widely used, later version is the Wisconsin Inventory of Science Processes (WISP). This instrument is designed to measure a student's understanding of scientific processes. Welch analyzed books by Beveridge (The Art of Scientific Investigation), Conant (Science and Common Sense), Kemeny (A Philosopher Looks at Science), Lachman (The Foundations of Science), Nash (The Nature of the Natural Sciences), and Wilson (An Introduction to Scientific Research), looking for elements of scientific processes. Elements that appeared in three or more of the six references were used to develop instrument items (Welch, no date). A revised version of the instrument was used in the evaluation study of Harvard Project Physics.

Six researchers used this instrument in their research on the effects of science laboratory work. [A seventh researcher (Rogers, 1972) used a Processes of Science Test.] Two (Dawson, 1975; Cannon, 1976) reported findings of no significant difference. One (M. O. Smith, 1972) reported results favoring the non-laboratory group. Three (Spears and Zollman, 1977; Stekel, 1971; and Whitten, 1971) reported significant increases in the understanding of science as indicated by the instrument.

The research reported by Spears and Zollman (1977) focused on the use of laboratories intended to provide students with experiences that would aid in understanding the processes of science as well as the content of science. Students were placed in either a structured laboratory situation (detailed procedures were provided) or in an unstructured one (objective was specified but procedures were decided by the student). Using the intellectual model of Piaget, Spears and Zollman hypothesized that if students were not at the level of formal operations, they could not be expected to devise and understand the process of science, a formal-operational procedure (p. 34). Students in unstructured laboratories were given the problem and told what equipment was available but they had to decide for themselves about how to take data, how much data to take, how to treat the data, how to interpret the results, how to present the results, etc. (p. 34).

The Inventory of Science Processes was given both as a pre-test, during the first week of the semester, and as a post-test, during the last week. Pre-test score, laboratory grade, and lecture instructor were used as covariates in the data analysis. Adjusted post-test scores were compared as to type of laboratory involvement. When the adjusted scores were analyzed, no differences were found for the components of the SPI: assumptions, nature of outcomes, and ethics and goals. Significant differences (.05) did occur in the fourth component, activities, with students in the structured laboratory scoring higher in this area. (p. 36).

Spears and Zollman speculated that, because many of the students in the unstructured laboratory were not at the formal operations level, they

were intellectually unprepared to perform the activities of scientists while those in the structured laboratory were led through these activities many times. The structured laboratory provided examples of activities of scientists, causing the students to learn better the process of science (pp. 36-37).

However, as the investigators point out (p. 34), this research leaves unanswered the question of whether laboratory involvement itself contributes to an understanding of the process of science. Another point to be considered is whether or not the process of science is unchanging. The references from which Welch developed test items were published in the 1950's and 1960's. Spears and Zollman (1977) identified four components of the test: assumptions, nature of outcomes, ethics and goals, and activities. If the process of science has not changed, it seems that public perception of the component "ethics and goals" has changed over the years. Citizens are no longer so willing to consider science as amoral. Does this change in public perception have any implications for the use of the instrument in secondary school and college science classes? The crucial question is probably the one which Spears and Zollman reported they did not investigate: whether laboratory involvement itself contributes to an understanding of the process of science. Data from the study by M. O. Smith (1972) indicated that "vicarious experimentation" was more effective than conventional laboratory work in physical science for the non-science majors involved in his study.

Test on Understanding Science. A third, frequently used, instrument was the Test on Understanding Science (TOUS), developed by Cooley and Klopfer (1963). The opening statement of the test directions reads "This is a test of your general knowledge about science, scientists, and the ways in which scientists do their work" (Form W, 1961). This instrument was developed for use in the History of Science Cases (HOSC) for High Schools Instruction Project, Harvard University, and a description of its development is available in a journal article (Cooley and Klopfer, 1963).

Eighteen themes, grouped into three areas, were identified by Cooley and Klopfer as important components of an understanding of science and scientists. These are shown below, as listed in the journal article (p. 74).

Area I. Understanding about the scientific enterprise
1. Human element in science
2. Communication among scientists
3. Scientific societies
4. Instruments
5. Money
6. International character of science
7. Interaction of science and society

Area II Understanding about scientists
1. Generalizations about scientists as people
2. Institutional pressures on scientists
3. Abilities needed by scientists

Area III Understandings about the methods and aims of science
1. Generalities about scientific methods

2. Tactics and strategy of sciencing
3. Theories and models
4. Aims of science
5. Accumulation and falsification
6. Controversies in science
7. Science and technology
8. Unity and interdependence of the sciences (1963, p. 74)

In the four dissertation studies in which use of the TOUS was reported, three researchers (Baxter, 1969; A. E. Smith, 1971; Sherman, 1969) reported no significant differences. The fourth reported that the students in the experimental group (a revised, general education, laboratory course in physical science) exhibited significant gains in TOUS scores, even when differences in ability, scholastic achievement, background knowledge, or skill were covaried out of the analysis, and concluded that the laboratory exercises had made an important contribution to student knowledge as tested by the TOUS instrument (Whitten, 1971).

However, the question persists: Does a science course have to contain a laboratory component for students to exhibit gain scores on the TOUS? The project for which the test was developed included laboratory experiments. The method by which these experiments was carried out was determined by the teacher and could involve the whole class, could be done as demonstrations, or could be done as projects by some students (Klopfer, 1960, p. 1-4). Klopfer urged the teachers using the HOSC guide to allow their students to participate in experiments similar to the ones actually done by the participants in the particular science case being studied. However, the HOSC method had as its primary emphasis enabling students to learn about science and scientists and not as a vehicle for learning science subject matter (Klopfer, 1960, p. 1-4), nor (one may assume) as a vehicle for learning laboratory skills.

A more promising approach may be to design an instrument specifically to detect the impact of the role of the laboratory on possible changes in understanding of the nature of science. None of the three instruments just discussed (Watson-Glaser, WISP, TOUS) was developed primarily to evaluate the role of the laboratory on critical thinking, on understanding of the process of science, or on knowledge of science, scientists, and the ways in which scientists work.

When studies focused on psychomotor skills or manipulative abilities (Pickering's "finger skills") useful in the science laboratory are considered, it is not surprising that they failed to fall into clusters based on instruments used. Because much of the research consisted of abstracts of dissertations as reported in Dissertation Abstracts International, the information on instruments and/or methodology was brief. Many researchers reported the use of a laboratory performance test that they had designed. Some evaluated performance in a laboratory activity (actual observation or analysis of a videotape of the technique); others looked at precision of results obtained. (Is it not possible to obtain reasonably accurate results with a less-than-adequate technique?) One investigator (Sullivan, 1972), working with ninth grade students, specified

that he evaluated motor coordination, manual dexterity, and finger dexterity. Others were more global in their descriptions.

Do the purposes for which laboratory activities in science are used vary with the educational level of the students? Information from the NSF case studies project (Stake et al; 1978) indicates that instruction in science is viewed differently in elementary and secondary schools. In elementary schools, science is fun and for all students. In secondary schools, science is perceived as being difficult and for the intellectually elite. Certainly college science courses appear to be of two types: for the major and for the purpose of general education of non-science majors.

Much of the research on the role of the laboratory involved college students enrolled in general education-type science courses. Is this the educational population we should be studying? Presumably it is and for reasons other than those of having a sufficiently large number of students involved for data analysis purposes. If the scientific establishment is to continue to function, it must be adequately funded. Funding is needed both for research and for education of prospective scientists and technicians. And, directly or indirectly, the general public has to approve such funding.

Another question is: Do we use laboratory activities for different purposes in high school science classes than in college science classes? Or, do we treat high school science students as miniature versions of college students majoring in science? Perhaps the approach varies with the secondary school science course being considered. Junior high school or middle school science and high school biology appear to have more of a "general education" flavor than do chemistry and physics. Perhaps, also, this brings us back again to Hurd's concern of science for the scientist or science for the citizen. If the purposes for which we teach science differ, do the behaviors and outcomes we look for and the methods we use to measure these outcomes also differ?

The review of the literature did not result in the identification of any studies in which the researcher asked teachers "Why do you teach science?" or "Why do you use laboratory activities in science?" Glovinsky (1962) investigated the status and extent of non-laboratory science courses in large American public school systems. He sent a 22-item questionnaire to 87 systems and received usable data from 76 of these, representing 45 states, and more than 700,000 science students, and more than 20,000 science classes. Laboratory work was used by 13,000 classes while 7,000 were of the non-laboratory variety. Glovinsky reported that the most common non-laboratory courses were general science, physiology, physical science, and physiography, with the oldest non-laboratory course being general science. Non-laboratory courses appeared to have originated because of lack of laboratory space. Many non-laboratory courses were designed for the slow learner.

The lack of laboratory space is a problem that often is not easily solved. However, providing non-laboratory courses for slow learners seems contradictory to current views about learning and instruction in which direct involvement with concrete objects is advocated.

One needs to keep in mind that Glovinsky's research was completed in 1962. However, the national survey completed by personnel at the Research Triangle (Weiss, 1978) is more recent. Data from this national survey indicate that only 48% of the science classes used manipulative or hands-on activities in science at least once a week. In addition, 9% of the science classes never used manipulative materials and another 14% did so less than once a month (p. 107).

Perhaps we need to focus more closely on that portion of Weiss's sample of science teachers who used hands-on manipulative or laboratory materials at least once a week (35%) or just about daily (13%) to determine what factors encourage or permit this approach to science teaching. What variables can be identified as being important: teacher preparation, participation in NSF institutes, personality factors, personal educational philosophy, administrative support, curriculum being used, community expectations, or other?

For years we have been concerned, in science education research, about the role of the laboratory. From national survey data we can see that the laboratory is not very important, judging by frequency of use, to 44% of the science teachers surveyed. Before the laboratory can make a difference, it has to be used.

While we are conducting research, we probably should also check on the 44% who use manipulative materials or the laboratory once a month or less (and perhaps also try to check on the 8% who did not respond). What problems do they face or what barriers do they perceive that cause them to neglect this instructional technique in their science classes? Do the causes stem from the immediate situation, from their pre-service training, or from a combination of factors? Do they consider laboratory experiences as being necessary for their science students? If so, for what reasons? How do the reasons these teachers give for teaching science and the goals they hold for their students differ from those of the teachers who make frequent use of the laboratory (at least once a week or more often)? Do they fail to use laboratory activities because they have never used them? Or have they had problems with discipline and are therefore reluctant to allow students the freedom to move about the room and talk that laboratory activities permit? Or are there other reasons for the non-use? Case study data (Stake et al., 1978) provide information that laboratory work is deemphasized because of expense, vandalism, and other control problems, along with an emphasis on course outcomes that show up on tests. However, "deemphasis" indicates a change in emphasis. We need also to be concerned about those science teachers who have never emphasized the use of the laboratory in their instruction.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The use of the laboratory for teaching science has been a concern of the science education community for many years. Researchers have been investigating the contributions of the laboratory to education in science ever since the 1930's, if not earlier. Despite this long history of investigation, science educators are unable to provide a large amount of evidence in support of the contention that laboratory work should continue in science classes, based on its contributions to various aims of science education. There is a large amount of opinion literature in favor of the use of the laboratory, with most of the authors assuming that the necessity of laboratory work is obvious and that what we need to be concerned about is how to improve upon what we are already doing.

There are critics of the use of the laboratory, both within and outside of the science education community. Administrators and teachers of other disciplines consider the laboratory expensive in terms of equipment, facilities, and teacher and pupil scheduling. Some science teachers consider the laboratory to be a problem in terms of time and effort involved in preparation and maintenance, as well as by lack of funds in terms of classroom management. They perceive themselves to be handicapped by lack of funds to buy materials when the need arises, as well as to repair and replace equipment and supplies and maintain the facilities. There is evidence that elementary school teachers do not feel well-prepared to teach science and their administrators do not consider themselves capable of providing teachers with assistance in the area of science. Scientists and science educators decry the use of cookbook-type, verification laboratories and advocate laboratory activities that are designed to convey to pupils the nature of science, its methods, and the spirit that pervades science.

While science teachers are being told that such goals for science instruction are important, they are also confronted with the pressures of the "back to the basics" movement, which appears to translate as more emphasis on educational accountability. Being accountable appears to mean, to many systems, an increase in achievement test scores of pupils. Most of the assessment of achievement takes place in the form of paper and pencil tests, usually of the multiple-choice variety. These test questions may not measure, accurately if at all, the kinds of objectives of science teaching that are promoted by laboratory experiences.

There is a long history of college domination of secondary school science--including the role of the laboratory, dating from the influence of German university science methodology in chemistry teaching and Harvard's "Descriptive List" in physics -- through the involvement of scientists in the science course improvement project activities funded by the National Science Foundation in the 1950's and 1960's. Although the science course improvement project materials emphasize inquiry and active involvement with concrete materials (especially for elementary school pupils), secondary teachers report lecture and discussion as the most frequently used teaching techniques, with less than half of the science teachers sampled in the

national survey (Weiss, 1978) indicating they use laboratory activities or manipulative materials once a week. Time for science in the elementary school is decreasing. At both elementary and secondary levels, the textbook appears to be the curriculum.

If these findings from the three large studies funded by the National Science Foundation are correct, where is the evidence for college domination in the 70's and 80's? It still appears in high school science courses in chemistry and physics in the emphasis on preparation for college science. Biology still appears to have a general education aspect to it, although advanced biology courses probably also reflect the preparation-for-college-science aspect of high school science teaching.

What appears to be emphasized in many high school science courses is science content rather than the spirit of the scientific enterprise. A description of what appears to take place in social studies classrooms fits the situation in science classrooms as well:

> The teachers' view of the textbook as authoritative undoubtedly stands in the way of their involving students in inquiry. But that is not the only factor. The hands-on, experience-centered learning of many inquiry-oriented curricula is seen as too demanding of students; too much is often expected of students at their level of intellectual developement and, probably even more important, self-discipline. From such a stance, inquiry teching is nonproductive. Time is wasted when students are allowed to formulate problems and pursue their own answers; and the few hours for instruction are too precious to be squandered in that way. There is so much content to be learned.
>
> (What are the Needs. . ., 1980, p. 8)

If the accumulation of content is the primary objective for teaching science, it is no wonder that laboratory activities are not used more often and that those activities that do take place are more frequently of the verification/illustration type rather than activities conveying the nature and spirit of science. Nor should it surprise anyone that the results of paper and pencil tests designed to assess the retention of cognitive information do not provide much support for the use of the laboratory.

Some of the individuals who advocate the use of the laboratory in science teaching appear to hold the idea that laboratory work is valuable for transfer of training. Through laboratory activities, students will come to understand the procedures of scientific investigation, including the control of certain variables, careful observation and recording of data, and the development of conclusions. Five major types of outcomes have been identified as resulting from participation in laboratory activities: the development of skills, concepts, cognitive abilities, understanding the nature of science, and attitudes (Shulman and Tamir, 1973).

A panel representing the scientific community provided an additional set of contributions of laboratory work (report of the panel representing the National Research Council of the National Academy of Sciences in

What are the Needs. . ., 1980). They wrote that laboratory work (1) provides personal experiences for students to get answers to questions, (2) provides information almost impossible to convey in textbooks, (3) requires activity of students in a time when many young people lead increasingly passive lives, (4) results in scientific observations and experiments that frequently show the limitations and uncertainties of scientific procedures, and (5) is fun for most students because it enables them to be independent, active discoverers (p. 95).

If we believe that laboratory work produces such contributions, why are we unable to do a better job of gathering evidence that supports our belief? Responses to this question vary. Some of these responses, and related speculations, will be discussed in the recommendations section that follows.

Recommendations

To rephrase the question: If we believe so strongly in the value of laboratory activities in science courses, why are we unable to identify a large number of research studies in support of our belief? Factors contributing to this situation may be lumped into one of two categories: those dealing with the mechanics of conducting research and those dealing with the complexity of the real world of the schools in which the research takes place.

Factors related to research. These factors are not new or different and have been discussed before, by many persons. A recent discussion was presented by Hofstein and Lunetta in their position paper for the 1980 meeting of the National Association for Research in Science Teaching (NARST).

Most of the research has been of the dissertation variety. As such, it usually represents an individual's first attempt at research and may exhibit one or more of the following defects:

Inadequate research design

Inappropriate statistical treatment of data

Relatively small sample

Relatively limited amount of time involved in treatment

Incomplete reporting of experimental treatment(s)

Inadequate description of "traditional" method or of the activities of the control group

Use of inappropriate instruments to measure changes, results

Lack of description of aptitudes, abilities of students involved

Failure to determine, and make appropriate use of, previous laboratory experiences (both amount and kind) of students

Lack of consideration of teacher behavior, classroom learning environment, materials, and other resources involved in the teaching-learning situation

(Readers who wish additional discussion of the topic of problems related to research on teaching methods may wish to review the material cited from McKeachie on pages 74 to 75 in this review or the section entitled "Some Additional Remarks about Research on Laboratory Instruction" pp. 92-105.)

Again, because much of the research is conducted by graduate students as a dissertation requirement, research on the role of the laboratory tends to be of the one-shot-study variety. Follow-up studies are lacking and only a few of the studies involve post-testing for retention after an extended period of time has separated the treatment and the post-test. And, as McKeachie pointed out, the researchers seldom follow up the experimental group students to determine if the treatment resulted in changes in other courses or in the program of studies they follow.

It is possible to say, as Hofstein and Lunetta did (1980, p. 3), ". . .as of yet there is insufficient data to make sweeping generalizations on the optimal role of the laboratory in science teaching." While this may be true (How much data do we need to merit the "sufficient" criterion?), the statement does not provide guidance to persons wishing to investigate the role of the laboratory.

It is also possible that the data exist but that there is a problem of translation or communication between sub-groups within the science education research community. When the literature was reviewed for relevant citations, terms such as "laboratory activities," "science laboratories," "laboratory experiments," and "laboratory procedures" were used to identify documents and journal articles. In some of these documents and articles, there is discussion of the value of concrete experiences or hands-on science activities, especially for those students not yet at the level of formal operations, as described by Piaget. However, the researchers who are most interested in cognitive development, as characterized by Piaget and by learning theorists, present papers at sessions of professional meetings to an audience of their peers who have similar interests, while at other, concurrent sessions of these same meetings other researchers are presenting papers about research on teaching or instruction to their peers who have similar interests in instruction research. What needs to take place is communication between these sub-groups so that it is possible to identify areas of concern that both share and to locate information about techniques or findings in one area that can be profitably translated into the scope of the other sub-group.

Recommendations related to the mechanics of research. What recommendations should be made to researchers? A number of these have been implied in the preceding discussion.

- Researchers should be familiar with--and avoid committing--those errors in research design and methodology elaborated by Curtis (1971b) (see page 95 in this review).

- Researchers should be wary of the pitfalls related to research on teaching methods identified by McKeachie (1963) (see page 74 in this review).

- Researchers need to make certain the instruments they use to measure outcomes are valid, reliable, and appropriate for their purposes. They need to make certain there is a valid and logical connection between the instructional procedures being used and the test(s) chosen to measure the effect(s) of these procedures.

- Research needs to be done to develop more appropriate instruments for measuring the various possible outcomes of laboratory instruction. Just as Kruglak worked to develop laboratory performance tests for use in college physics classes, other science educators need to focus on laboratory performance tests for the other sciences and to develop such instruments at a level appropriate for use with middle/junior high school and senior high school science classes.

- Long-term studies need to be done to determine the effects of laboratory instruction. This may not be possible with a college student population but such studies could be done as pupils move through their secondary education.

- Researchers interested in the effect of science laboratory work on attitudes need to make a clear distinction concerning the type of attitudes being studied, i.e., attitudes toward science or scientific attitudes.

- More research needs to be done concerning the effects of laboratory activities in science on the performance of minority students as well as on the performance of students classified as low-average or below-average in intelligence.

- More research needs to be done in which the classroom climate and instructional materials involved (textbooks, laboratory manuals, etc.) are studied to determine what effects these factors have on the outcomes of laboratory instruction.

- Communication channels need to be developed not only between researchers and classroom teachers but between the various sub-groups of researchers.

- Those involved in research on the role of the laboratory need to make certain that the objectives they postulate for laboratory work are both achievable and measurable within the constraints of the research design.

- Research needs to be done in which such factors as students' preferred learning styles, locus of control, self-image are investigated related to their relationship to the outcomes of laboratory instruction.

- More research needs to be done with elementary school pupils in activity-oriented science programs to determine whether or not such experiences have any lasting influence as these students do, or do not, elect to take science at the secondary school level.

- Research needs to be done to determine if participation in laboratory science courses has any spill-over effects which influence students' behavior in their other courses.

Factors related to the schools. Data from the NSF studies, particularly from the national survey by Weiss (1978) and the case studies by Stake et al. (1978) show that laboratory work and/or hands-on science activities are used less frequently than science educators would desire. Teachers talk of student apathy and of problems involved in managing laboratory activities, as well as in maintaining science facilities and replacing equipment and supplies. The use of laboratory instruction and the inquiry approach appear to be diminishing. While laboratory-centered science courses are more difficult to teach than are those involving primarily teacher lecture and demonstration, the emphasis on accountability and the push for back-to-the-basics should not be used as convenient scape-goats for de-emphasizing laboratory work. Teachers and schools do need to be held accountable. Schools need to be intellectually stimulating places for both teachers and students.

Frequently the need to be accountable has been translated as the need for an increase in test scores. However, complex ideas and relationships are difficult to test in a multiple-choice format and so the areas emphasized are those which can be measured by such tests. Over-reliance on those aspects of the curriculum (in science or in any other subject) that can be most readily expressed in simple numerical scores sets limits on what is to be learned (What are the Needs. . ., 1980, p. 113).

Objectives for teaching science are broader than just the accumulation of a store of factual information (some of which rapidly becomes out-dated). Critical thinking, problem solving, and getting a feeling for the nature of science and the scientific enterprise should be a part of the goals for teaching science. What happens to such goals and objectives when tests are written?

This problem was discussed at a conference on research and testing (Tyler and White, 1979). Tyler and White (p. 39) spoke to this point when they discussed science, citing some examples of science objectives; e.g.,

1) to understand certain basic scientific concepts and generalizations and use them in observing and explaining natural phenomena,

2) to carry out inquiries seeking to understand puzzling natural phenomena,

3) to make reasonable interpretations of data about natural phenomena obtained from experiments,

4) to know and use dependable sources of information relating to science, and

5) skill in the use of scientific instruments and other apparatus.

In discussing problems of testing, teaching, and learning, Tyler and White identified two assumptions that, in their opinion, continue to confuse and impede the improvement of educational testing; i.e., (1) the notion that educational objectives of schools and colleges are chiefly skills, and (2) the assumption that the student's attainment of the important educational objectives can be appraised by the use of paper and pencil tests.

Tyler and White do not consider either assumption to be tenable. According to them, the notion that a single test score can appraise either the program or the student is an absurd conception. It should be obvious that a paper and pencil test is unlikely to indicate the attainment of some of the goals they specified (pp. 39-41). Tyler and White have suggested that, in test construction, it is necessary to identify and define each major educational objective students are expected to attain. However, often only the content to be covered is identified and not what the students are to do with the content.

This discussion can be related to the role of the laboratory through the finding that much of the research in this area has focused on the measurement of cognitive gains -- through the use of paper and pencil tests. If one is in agreement with Tyler and White's argument, it is not surprising that these studies did not result in positive findings at a level of significance.

Recommendations related to the schools. Teaching is a complex activity. Individuals, both teachers and students, bring to the teaching-learning situation factors and variables that are not always subject to the control of the experimenter. However, when they have measured for intelligence, aptitude, or some other variables and applied the appropriate statistical analyses to the data, researchers frequently act as if they have a tightly controlled educational experiment. This is probably naive.

As this review was being prepared, one of the questions which came to mind was whether science teachers and science education researchers assumed different outcomes for the use of the laboratory. Do high school science teachers and science educators make different uses of science subject matter? How frequently are science teachers made real partners in the research enterprise?

- Research needs to be done to determine the amount of congruence between science teachers and science education researchers relative to the anticipated outcomes for the use of the laboratory in science classes.

- Not only do researchers need to communicate the implications of their research for classroom practice, they also need

to work to make science teachers partners in their research rather than only the objects of study.

- Research needs to be done to determine the effects of barriers, real or perceived, to the use of science laboratory activities or hands-on science programs on the implementation and use of such activities and programs.

- Research needs to be done to determine if the speculation that inquiry teaching is not appropriate for all students is valid in terms of students' level of cognitive development, ability to exercise self-discipline, etc.

- Research needs to be done to develop methods for assessing the outcomes of laboratory instruction that are not measurable by paper and pencil tests.

- Research needs to be done to identify laboratory activities that will enable average and below-average students to gain an understanding of science principles and processes underlying the technology with which they are familiar.

- Research needs to be done to identify or to develop activities and mechanisms for use in teacher education programs (pre-service and in-service) that will enable science teachers to develop skills in improvising so they are able to teach laboratory-centered science courses, even when faced with lack of funds for purchase of materials and equipment.

and, finally,

- RESEARCH NEEDS TO BE DONE TO FIND OUT "WHAT PRACTICES ARE EFFECTIVE WITH WHAT STUDENTS FOR WHAT PURPOSE UNDER WHAT CONDITIONS. . ." (What are the Needs. . ., 1980, p. 177)

rather than continuing to attempt to prove that method X is superior to method Y.

BIBLIOGRAPHY

Advisory Council on College Chemistry. "Alternatives and Supplements to the Introductory Laboratory." Report of a Conference of the General Chemistry Committee. Washington, D.C., 1966. (Mimeographed.)

Allison, Robert D. "An Investigation into the Attitudes toward Science of College Chemistry Students as a Function of Laboratory Experience." Dissertation Abstracts, Vol. 33: 7, p. 3422A, January, 1973.

American Association for the Advancement of Science Cooperative Committee on the Teaching of Science and Mathematics. The Effectiveness of Science Teaching, a forum held in cooperation with 1947 meeting of the American Association for the Advancement of Science, Chicago.

Anderson, Kenneth E. "An Annual Review of Research in Science Teaching," Science Education 38(1): 6-38, February, 1954.

Anderson, Kenneth E. "Science Instruction and the Laboratory," School Science & Mathematics XLIX (430): 367-370, May, 1949.

Anderson, Kenneth E., et al. "Second Annual Review of Research in Science Teaching." Science Education 38(5): 333-365, December, 1954.

Anderson, Ronald D. Review of Research in Science Education for the Year 1971. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education Research Review Series. Science Paper 10, April, 1973. (ERIC Document Reproduction Service No. ED 077 775)

Anderson, Ronald D. "Using the Laboratory to Teach the Nature of Science," The American Biology Teacher 30: 633-636, October, 1968.

Andrews, Donald H. Educating a Chemist. Baltimore, MD: Johns Hopkins University, 1957.

Andriette, W. R. "Differences in Retention Between Populations of Seventh Grade Science Students Taught by Two Methods of Instruction: Small Group Laboratory and Teacher Demonstration." Dissertation Abstracts, Vol. 31: 6, p. 2753A, 1970.

Appleman, Ronald E. "A Comparative Study of the Cognitive Effects of the Use of Take Home Laboratory Materials on Student Achievement in College Level Physical Science Classes." Dissertation Abstracts, Vol. 28: 12, p. 4927A, June, 1968.

Atkin, J. Myron "Science in the Elementary School" Review of Educational Research 34(3): 263-272, June 1964.

Babikian, Yeghia. "An Empirical Investigation to Determine the Relative Effectiveness of Discovery, Laboratory, and Expository Methods of Teaching Science Concepts," Journal of Research in Science Teaching 8(3): 201-209, 1971.

Bailey, Orris G. "A Comparison of Achievement in the Concepts of Fundamentals of Chemistry of Eleventh-Grade Senior Physical Science Students Taught by Laboratory Versus Enriched Lecture-Demonstration Methods of Instruction." Dissertation Abstracts, Vol. 26:3, p. 1442A, September, 1965.

Baillie, John H. Laboratory Experiences for Disadvantaged Youth in the Middle School. (ERIC Document Reproduction Service No. 035 687)

Baker, Glenn E. "A Comparison of the Problem-Solving Method of Project Construction and Conventional Methods in Teaching the Laboratory of a College Course in Beginning Electricity." Dissertation Abstracts, Vol. 27: 10, p. 3354A, April, 1967.

Balzer, A. L., T. P. Evans, and P. E. Blosser. A Review of Research on Teacher Behavior Relating to Science Education. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education, 1973. (ERIC Document Reproduction Service No. ED 087 638)

Barnes, George, and George B. Barnes. "Students' Scores on Piaget-Type Questionnaires Before and After Taking One Semester of College Physics," American Journal of Physics 46(8): 807-809, August, 1978.

Barnes, Lehman W. Jr. "The Nature and Extent of Laboratory Instruction in Selected Modern High School Biology Classes." Dissertation Abstracts, Vol. 27(9): p. 2931A, March, 1967.

Barnes, Lehman E., and Addison E. Lee. "The Development of a Student Checklist to Determine Laboratory Practices in High School Biology." (Mimeographed, no date.)

Barnes, Marjorie R. P. "An Experimental Study of the Use of Programmed Instruction in a University Physical Science Laboratory." Dissertation Abstracts, Vol. 30: 5, p. 1907A, 1969.

Basmajian, Ronald K. "The Relationship between Piagetian Cognitive Maturity and Scholastic Success of Students Enrolled in an Audio-Tutorial Biology Program." Dissertation Abstracts, Vol. 39: 1, p. 210A, July, 1978.

Bates, Gary C. "The Role of the Laboratory in Secondary School Science Programs," in What Research Says to the Teacher, ed. Mary Budd Rowe, Vol. I: 55-82, Washington, D.C.: National Science Teachers Association, 1978. (ERIC Document Reproduction Service No. ED 148 628)

Baxter, Kimball W. "A Comparative Study of the Effectiveness of Three Methods of Teaching a General Education Physical Science Course." Dissertation Abstracts, Vol. 30:2, p. 482-A, August, 1969.

Beasley, Warren F. "The Effect of Physical and Mental Practice of Psychomotor Skills on Chemistry Student Laboratory Performance." Dissertation Abstracts, Vol. 39: 9, p. 5428A, March, 1979a.

Beasley, W. F. "Laboratory Psychomotor Skill Development Using Physical and Mental Practice Strategies," Research in Science Education (8): 135-144, 1978.

Beasley, Warren F. "The Effect of Physical and Mental Practice of Psychomotor Skills on Chemistry Student Laboratory Performance," Journal of Research in Science Teaching 16(5): 473-479, 1979b.

Beisenherz, Paul C., and Roger G. Olstad. "The Use of Laboratory Instruction in High School Biology," The American Biology Teacher 42(3): 166-168, 175, March, 1980.

Belanger, Maurice. "Learning Studies in Science Education." Review of Educational Research 39(4): 377-395, 1971.

Belanger, Maurice. "Methodology of Educational Research in Science and Mathematics." Review of Educational Research 34(3): 374-390, June, 1964.

Ben-Zvi, R., A. Hofstein, D. Samuel, and R. F. Kempa. "The Attitude of High School Students Towards the Use of Filmed Experiments," Journal of Chemical Education 53(9): 575-576, Sept., 1976.

Berger, Toby E. "Evaluation of an Environmental Science Laboratory Curriculum." Dissertation Abstracts, Vol. 33: 8, p. 4196A, Feb., 1973.

Beun, J. A. "Experiences With a Free Undergraduate Laboratory," American Journal of Physics 39 (11): 1353-1356, Nov., 1971.

Bingham, N. Eldred and Joe Y. West. "Arms and Purpose of Science Teaching" Review of Educational Research 18(4): 297-314, October, 1948.

Bingman, Richard M. "Inquiry Objectives in the Teaching of Biology." Vol. I(2), Sept., 1969. Kansas City, MO: Mid-continent Regional Educational Laboratory. (Position Paper.) (ERIC Document Reproduction Service No. ED 037 343)

Blackwood, Paul E. and Kenneth E. Brown. "Science Education Research Studies-1954." Science Education 39(5): 372-389, December, 1955.

Blick, David J. "Digest of Investigations in the Teaching of Science," 1937-1943. Storrs, CT: University of Connecticut. (Mimeographed, no date.)

Blomberg, Karin J. "A Study of the Effectiveness of Three Methods for Teaching Science in the Sixth Grade." Dissertation Abstracts, Vol. 35: 6, p. 3290, Dec., 1974.

Boeck, Clarence H. et al. "Fourth Annual Review of Research in Science Teaching." Science Education 40(5): 337-357, December, 1956.

Boenig, Robert W. Research in Science Education 1938 through 1947. New York: Teachers College Press, 1969.

Boghai, Davar M. "A Comparison of the Effects of Laboratory and Discussion Sequences on Learning College Chemistry." Dissertation Abstracts, Vol. 39: 10, p. 6045A, April, 1979.

Boud, D. J., J. G. Dunn, and T. Kennedy. "Trends in the Teaching of Laboratory Work," Journal of Chemical Education 57(6): 456-457, June, 1980.

Bradley, R. C., N. W. Earp, and Troy Sullivan. "A Review of Fifty Years of Laboratory Work," Science Education 50(2): 152-155, 1966.

Bradley, Robert H. "Is the Science Laboratory Necessary for General Education Science Courses?" Science Education 52(1): 58-66, Feb., 1968.

Bradley, Robert L. "Lecture Demonstration vs. Individual Laboratory Work in a Natural Science Course at Michigan State University." Dissertation Abstracts, Vol. 23: 12, p. 4568, June, 1963.

Brandwein, Paul, Jerome Metzner, Evelyn Morholt, Anne Rose, and Walter Rosen. "Teaching High School Biology." A Guide to Working with Potential Biologists, Washington, D.C.: American Institute of Biological Sciences, Biological Sciences Curriculum Study Bulletin No. 2, 1962.

Bredderman, Ted. "A Meta-Analysis of Elementary School Science Process Curriculum Studies, Preliminary Report." Paper presented at the annual meeting of American Educational Research Association, San Francisco, CA, April, 1979.

Breed, Frederick S. "Spelling, Handwriting, Social Studies, Character Education, Geography, and Natural Science." Review of Educational Research 1(4): 276-293, October, 1931.

Briggs, Leslie J. and David Angell. "Programed Instruction in Science and Mathematics." Review of Educational Research, Vol. 34(3): 354-373, June, 1964.

Bronowski, J. The Common Sense of Science. Cambridge, MA: Harvard University Press, 1958.

Brosius, Edward J. "A Comparison of Two Methods of Laboratory Instruction in Tenth-Grade Biology." Dissertation Abstracts, Vol. 26: 6, p. 3170A, 1965.

Brown, Kenneth E., Paul E. Blackwood, and Philip G. Johnson. "Science Education Research Studies-1953." Science Education 39(2): 141-156, March, 1955.

Brown, Sanborn C. "Do College Students Benefit from High School Laboratory Courses?" American Journal of Physics 26: 334-337, 1958.

Brown, William R. "Teacher Competencies and Characteristics in a Science Preservice Teacher Education Project." Unpublished Doctor's dissertation, The Ohio State University, 1972. (ERIC Document Reproduction Service No. ED 059 864)

BSCS "Human Sciences: A Developmental Approach to Adolescent Education." Boulder, CO: Biological Sciences Curriculum Study, 1973. (ERIC Reproduction Service No. ED 079 107)

Buck, Jacqueline V. and George G. Mallinson. "Some Implications of Recent Research in the Teaching of Science at the Elementary School Level." Science Education 38(1): 81-101, February, 1954.

Burnett, R. Will. "Academic and Professional Preparation Science Teachers." Review of Educational Research 34(3): 313-321, June, 1964.

Burnett, R. Will and Lillian Gragg. "Teacher Education in Science and Mathematics." Review of Educational Research 18(4): 364-367, October, 1948.

Burnett, R. Will and Theodore Porowski. "Instructional Procedures in Science." Review of Educational Research 21(4): 264-278. October, 1951.

Buros, Oscar K., ed. The Fifth Mental Measurements Yearbook. Highland Park, New Jersey: The Gryphon Press, 1959.

Bybee, Rodger W. "The Effectiveness of an Individualized Approach to a General Education Earth Science Laboratory," Science Education 54: 157-161, 1970.

Calentine, Robert L. "A Comparative Study of Two Laboratory Teaching Methods." Final report, CORD Project. River Falls, WI: Wisconsin State University, December, 1969. (ERIC Document Reproduction Service No. ED 053 985)

California State Department of Education. "Science Curriculum Development in the Secondary Schools." Report of the Statewide Advisory Committee on Science Instruction in the High School. Sacramento, CA: State Department of Education, April, 1964.

Callahan, Joseph F., and Leonard H. Clark. Foundations of Education, Planning for Competence. New York: MacMillan Publishing Co., 1977.

Campbell, Thomas C. "An Evaluation of a Learning Cycle Intervention Strategy for Enhancing the Use of Formal Operational Thought by Beginning College Physics Students." Dissertation Abstracts, Vol. 38: 7, p. 3903A, 1978.

Cannon, Richard A. "A Comparison of Two Laboratory Methods Investigating Interest and the Understanding of the Process of Science in a General Education Physical Science Course." Dissertation Abstracts, Vol. 36: 7, p. 4379A, 1976.

Cavin, Claudin S. "A Study of Some Computer - Simulated Experiments in a College General Chemistry Laboratory Course." Dissertation Abstracts, Vol. 38(5): 2683A, November, 1977.

Charen, George. "Laboratory Methods Build Attitudes." Science Education 50(1): 54-57, 1966.

Clark, George M. "Life Sciences in the Middle School." Boulder, CO: Biological Sciences Curriculum Study Center, Special Publication No. 7, 1969.

Cooley, W. and Leopold E. Klopfer. "The Evaluation of Specific Educational Innovations," Journal of Research in Science Teaching 1: 73-80, 1963.

Comber, L. C., and J. P. Keeves. Science Education in Nineteen Countries, International Studies in Evaluation I. New York: John Wiley & Sons, Inc., 1973. (ERIC Document Reproduction Service No. ED 081 639)

Conway, Thomas E. "An Experimental Study Comparing Achievement and Preference Between a Traditional Method and a Programmed General Biology Laboratory." Dissertation Abstracts, Vol. 28: 4, p. 1338A, 1967.

Costa, Joseph J. "A Comparison of Achievement and Attitudes in College Chemistry Classes Having Direct Laboratory, Vicarious Laboratory or Written Descriptive Narrative Laboratory Experiences." Dissertation Abstracts, Vol. 34: 7, p. 3903, 1974.

Coulter, John C. "The Effectiveness of Inductive Laboratory, Inductive Demonstration, and Deductive Laboratory Instruction in Biology." Dissertation Abstracts, Vol. 26(8): 4494A, February, 1966a.

Coulter, John C. "The Effectiveness of Inductive Laboratory-Inductive Demonstration, and Deductive Laboratory in Biology." Journal of Research in Science Teaching 4: 185-186, 1966b.

Cravats, Monroe. "A Study of the Value of Laboratory Exercises in a General Science Class of Low I.Q. Students in New York City." Dissertation Abstracts, Vol. 27: 7, p. 2133A, 1969.

Crawford, Eugene and DeWayne Backhus. "The Effect of the Laboratory on the College Students' Understanding and Knowledge of Physical Science." Final Report, Project No. 8-F-075. Emporia, KS: Kansas State Teachers College, 1970. (ERIC Document Reproduction Service No. ED 042 609)

Cunningham, Harry A. "Lecture Demonstration Versus Individual Laboratory Method in Science Teaching--a Summary," Science Education 30(2): 70-82, March, 1946.

Cunningham, John, and David P. Butts. A Summary of Research in Science Education for the Years 1963-1964, Elementary School Level. Columbus,

OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education Research Review Series. Science Paper 5, January, 1970. (ERIC Document Reproduction Service No. 040 304)

Curtis, Francis D. A Digest of Investigations in the Teaching of Science in the Elementary and Secondary Schools, New York: Teachers College Press, 1931, reprinted 1971a.

Curtis, Francis D. "Curriculum Investigations at the Elementary-and Sewondary-School Levels: Science," Review of Educational Research 4(2): 165-167, April, 1934.

Curtis, Francis D. "Curriculum Investigations: Science," Review of Educational Research 7(2): 162-164, April, 1937.

Curtis, Francis D. Second Digest of Investigations in the Teaching of Science. New York: Teachers College Press, 1931, reprinted 1971b.

Curtis, Francis D. "Teaching of Science in Grades I through VI," Review of Educational Research 12(4): 369-374, October, 1942a.

Curtis, Francis D. "Teaching of Science in Grades VII, VIII, and IX," Review of Educational Research 12(4): 375-384, October, 1942b.

Curtis, Francis D. Third Digest of Investigations in the Teaching of Science. New York: Teachers College Press, 1938, reprinted 1971c.

Curtis, F. D. "Some Contributions of Educational Research to the Solution of Teaching Problems in the Science Laboratory," A Program for Teaching Science, 31st Yearbook of the National Society for the Study of Education, Part I, ed. G. M. Whipple. Chicago: The University of Chicago Press, 1932.

Curtis, Francis D. "Individual Laboratory Work Must Be Retained," The Science Teacher 17(2): 63-64, 82, 84, 86, April, 1950.

Damewood, Judith C. "Evaluation of a Physical Science Course for Prospective Elementary Teachers in Terms of Competence Attained in the Processes of Science." Dissertation Abstracts, Vol. 32: 6, p. 3112A, 1971.

Dawson, Joel C. "An Investigation of the Effects of Two Specific Instructional Strategies--Guided-Decision-Making and Conventional Direction-Following--on Critical Thinking Performance and Knowledge of the Processes of Science of Students Engaged in a College Biology Laboratory Course." Dissertation Abstracts, Vol. 36: 6, p. 3538A, 1975.

Dearden, Douglas M. "An Evaluation of the Laboratory and Supplementary Teaching Techiques Used in a College General Biology Course." Dissertation Abstracts, Vol. 20: 6, p. 2097A, 1959.

Dembo, Myron. Teaching for Learning: Applying Educational Psychology in the Classroom. Santa Monica, CA: Goodyear Publishing Co., 1977.

Dettrick, Graham W. "The Performance of 9 to 12 Year Old Children on Primary, Secondary and Multiplicative Classification Tasks: Implications for Teaching and Curriculum Design," Research in Science Education 8: 205-211, 1978.

Dickinson, Donald H. "Community College Students' Achievement and Attitude Change in Lecture Only, Lecture-Laboratory Approach to General Education Biological Science Courses." Dissertation Abstracts, Vol. 36: 9, p. 5968A, 1976.

Disinger, John F. "Student Development, Teacher Characteristics, and Class Characteristics in Junior High School Science." Unpublished Doctor's dissertation, The Ohio State University, 1971. (ERIC Document Reproduction Service No. ED 107 460)

Doran, Rodney L. "Assessing the Outcomes of Science Laboratory Activities," Science Education 62(3): 401-409, 1978.

Dorrance, Robert W. Jr. "Cognitive and Manipulative Skills as Outcomes of General Biology Laboratory Instruction." Dissertation Abstracts, Vol. 37: 1, p. 212-213A, 1976.

Downing, Elliot R. "A Comparison of the Lecture-Demonstration and the Laboratory Methods of Instruction in Science," School Review 33: 688-697, 1925.

Driscoll, Jerry A. "Development and Evaluation of Instructional Television Laboratories for General Education Chemistry." Dissertation Abstracts, Vol. 35: 4, p. 2071, 1974.

Dubravcic, Milan. "Practical Alternatives to Laboratory in a Basic Chemistry Course," Journal of Chemical Education 56(4): 235-237, April, 1979.

Dyrli, Odvard Egil. "Should We Scrap Lab-Centered Science Programs?" Learning 39: 34-35, February, 1981.

Edgar, Irvin T. "A Study of the Effects of Laboratory Centered Instruction on Student Critical Thinking Skills and Attitudes in Biology." Dissertation Abstracts, Vol. 29: 11, p. 3910A, 1969.

Educational Policies Commission. Education and the Spirit of Science. Washington, D.C.: National Education Association, 1966.

Egelston, Judy C. "Inductive vs. Traditional Methods of Teaching High School Biology Laboratory Experiments," Science Education 57(4): 467-477, 1973.

Egelston, Judy C. "An Observational Investigation of Classroom Behavior Under the Inductive and Traditional Methods of Teaching High School Biology Laboratories." Dissertation Abstracts, Vol. 32: 2, p. 818A, 1971.

Eglen J. R., and Kempa R. F. "Assessing Manipulative Skills in Practical Chemistry," The School Science Review 56(195): 261-273, December, 1974.

Emslie, Charles M. "Teaching Fourth and Sixth Grade Science Using Laboratory-Theory and Theory-Laboratory Sequence Methods of Instruction." Dissertation Abstracts, Vol. 32: 11, p. 6237A, 1972.

Engelhart, Max D. "Physical and Biological Sciences," Review of Educational Research 2(1): 21-28, February, 1932.

Fay, Paul J. "The History of Chemistry Teaching in American High Schools," Journal of Chemical Education 8(8): 1533-1562, August, 1931.

Fix, William T., and John W. Renner. "Chemistry and the Experiment in the Secondary Schools," Journal of Chemical Education 56(11): 737-740, November, 1979.

Fordham, Adrian. "The Interaction of Student Characteristics and Science Teaching on Student Perception of the Learning Environment," Research in Science Education 8: 89-98, 1978.

Francis, Ernest E. "An Analysis of Achievement in a College Biology Audio-Tutorial Program." Dissertation Abstracts, Vol. 37: 9, p. 5727A, 1977.

Fraser, Thomas P. et al. "Review of Recent Research in the Teaching of Science at the College Level." Science Education 39(5): 357-371, December, 1955.

Fraser, Thomas P. et al. "Symposium: Needed Research in Science Education" Science Education 40(5): 363-387, December, 1956.

Furhman, M., V. Lunetta, S. Novick, and P. Tamir. "The Laboratory Structure and Task Analysis Inventory (LAI): A User's Handbook." Technical Report 14, Iowa City: Science Education Center, The University of Iowa, August, 1978. (ERIC Document Reproduction Service No. ED 166 002)

Gabel, Dorothy, Martin H. Kagen, and Robert D. Sherwood. "A Summary of Research in Science Education-1978." New York: John Wiley & Sons, Science Education 64(4): 429-568, September, 1980.

Gagne, Robert M. "The Learning Requirements for Enquiry," Journal of Research in Science Teaching 1: 144-153, 1963.

Gallagher, James J. A Summary of Research in Science Education for the Years of 1968-1969 Elementary School Level. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education Research Review Series. Science Paper 6, no date. (ERIC Document Reproduction Service No. ED 005 099)

Glass, Bentley. Remarks on the examination of the true function of laboratory work for the student. Minutes of the American Institute of Biological Sciences Biological Sciences Curriculum Study meeting of the Committee on Innovation in Laboratory Instruction, August 5-8, 1959. Columbus, OH: SMEAC Information Reference Center, NSF Archives. (Mimeographed.)

Glovinsky, Sanford J. "The Status and Extent of Non-Laboratory Science Courses in the Science Education Program of Secondary Schools in Selected Major School Systems of the United States." Dissertation Abstracts, Vol. 23: 3, p. 952, 1962.

Godomsky, Stephen F. Jr. "Programmed Instruction, Computer-Assisted Performance Problems, Open-Ended Experiments and Student Attitude and Problem Solving Ability in Physical Chemistry Laboratory." Dissertation Abstracts, Vol. 31: 11, p. 5873A, 1971.

Good, H. G. A History of American Education. New York: The Macmillian Co., 1956.

Grosmark, Jay W. "The Relationship Between Achievement and Laboratory Skills to the Number of Experiments Performed by the High School Chemistry Student." Dissertation Abstracts, Vol. 34: 6, p. 3176, 1973.

Grozier, Joseph E. Jr. "The Role of the Laboratory in Developing Positive Attitudes Toward Science in a College General Education Science Course for Nonscientists." Dissertation Abstracts, Vol. 30: 6, p. 2394A, 1969.

Gunsch, Leonhardt M. "A Comparison of Students' Achievement and Attitude Changes Resulting from a Laboratory and Non-Laboratory Approach to General Education Physical Science Courses." Dissertation Abstracts, Vol. 33: 2, p. 6290, 1972.

Haley, Suzanne B., and Ronald G. Good. "Concrete and Formal Operational Thought: Implications for College Biology," The American Biology Teacher 38: 407-412, 430, October, 1976.

Halyard, R. A., B. M. Pridemore, and C. B. Carpenter. "An Analysis of an Individualized Biology Laboratory in a Junior College." (Mimeographed, no date.)

Hamilton, Donald K. "The Relative Merits of Two Teaching Methods in Improving the Skills of Observation and Inference-Making of Seventh and Eighth Grade Science Students." Dissertation Abstracts, Vol. 27: 10, p. 3340A, 1967.

Hammack, Jerry K. "A Comparative Study of the Effects of Self-Paced and Lecture Laboratory Instruction on Achievement in General Studies Biology." Dissertation Abstracts, Vol. 35: 7, p. 4187-4188A, 1975.

Haney, Richard, Donald Neuman, D. Clark, and C. Smith. A Summary of Research in Science Education for the Years of 1965-1967,

Elementary School Level. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education Research Review Series. Science Paper 2, December, 1969. (ERIC Document Reproduction Service No. ED 038 554)

Hartford, Frederick Wm. "Laboratory-Related Development of Research Questioning Skills in Chemistry Students and Their Dependence Upon Piagetian Intellectual Development." Dissertation Abstracts, Vol. 41 (3): p. 1011A, September, 1980.

Hegarty, Elizabeth. "Levels of Scientific Enquiry in University Science Laboratory Classes: Implications for Curriculum Deliberations," Research in Science Education 8: 45-57, 1978.

Helgeson, Stanley L., Patricia E. Blosser, and Robert W. Howe. The Status of Pre-College Science, Mathematics and Social Studies Education (1955-1975 Edition). Washington D.C.: U.S. Government Printing Office. Science Education No. 78-73 (ERIC Document Reproduction Service No. ED 153 876)

Henry, Nelson B. Science Education in American Schools, 46th Yearbook of the National Society for the Study of Education, Part I. Chicago: The University of Chicago Press, 1947.

Henry, Nelson B. Rethinking Science Education, 59th Yearbook of the National Society for the Study of Education, Part I. Chicago: The University of Chicago Press, 1960. (ERIC Document Reproduction Service No. ED 012 233)

Herron, J. Dudley, H. H. Jaus, Van Neie, T. Luce, and T. O'Heron. "A Summary of Research in Science Education - 1974." Science Education, New York: John Wiley & Sons, 1975.

Herron, Marshall D. "The Nature of Scientific Enquiry," The School Review 79: 171-212, 1971.

Hincksman, N. G. "The Function of the School Laboratory." The Australian Science Teachers Journal 60(19): 81-86, December, 1973.

Hittle, David R. "Directed Discovery, Form of Presentation, and Laboratory Schedule for Nonscience Students in the Freshman Chemistry Laboratory." Dissertation Abstracts, Vol. 30: 10, p. 4292A, 1970.

Hoff, Darrel B. "A Comparison of a Directed Laboratory Versus an Enquiry Laboratory Versus a Nonlaboratory Approach to General Education College Astronomy." Dissertation Abstracts, Vol. 31: 6, 2755A, 1970.

Hofstein, Avi, Ruth Ben-Zvi, and David Samuel. "The Measurement of the Interest in, and Attitudes to, Laboratory Work Amongst Israeli High School Chemistry Students." Science Education 60(3): 401-411, 1976.

Hofstein, Avi, and Geoffrey Giddings. "Trends in the Assessment of Laboratory Performance in High School Instruction." Technical Report

20, Iowa City: Science Education Center, The University of Iowa, February, 1980.

Hofstein, Avi, and V. N. Lunetta. "The Role of the Laboratory in Science Teaching: Research Implications." Paper presented at the National Association for Research in Science Teaching annual meeting, Boston, MA, April, 1980. (ERIC Document Reproduction Service No. ED 188 912)

Holcomb, Charlie M. "The Effect of Degrees of Direction in the Qualitative Analysis Laboratory on Retention of Learning," Journal of Research in Science Teaching 8(2): 165-169, 1971.

Holloway, Dennis Jr. "A Study of the Effects of the Thirteen Colleges Curriculum Program Open-Ended Laboratory Experiences on the Critical Thinking Abilities and Attitudes Toward Science of College Freshmen." Dissertation Abstracts, Vol. 36: 7, p.222A, 1976.

Hughes, James E. "A Comparison of Lab Method Films with Traditional Instruction in the Introductory Physics Laboratory." Dissertation Abstracts, Vol. 32: 7, p. 3814, 1972.

Hughes, William R. "A Study of the Use of Computer Simulated Experiments in the Physics Classroom." Dissertation Abstracts, Vol. 34: 8, p. 4910A, February, 1974.

Humphreys, Alan H. "A Critical Analysis of the Use of Laboratories and Consultants in Junior High School Science Courses." Dissertation Abstracts, Vol. 23: 5, p. 1623, 1962.

Hurd, Paul DeHart. "Biological Education in American Secondary Schools 1890-1960." Washington, D.C.: American Institute of Biological Sciences, Biological Sciences Curriculum Study, No. 1, 1961. (ERIC Document Reproduction Service No. ED 010 991)

Hurd, Paul DeHart. Theory Into Action. Washington, D.C.: National Science Teachers Association, 1964. (ERIC Document Reproduction Service No. ED 011 000)

Hurd, Paul DeHart, and Mary Budd Rowe. "Science in the Secondary School," Review of Educational Research 34(3): 286-297, June, 1964.

Jacobson, Willard J. "Forty Years of Research in Science Education." Paper presented at the 47th annual Meeting of the National Association for Research in Science Teaching, Chicago, Illinois, April, 1974.

Jeffrey, Jack C. "Evaluation of Science Laboratory Instruction," Science Education 52(2): 186-194, March, 1967a.

Jeffrey, Jack C. "Identification of Objectives of the Chemistry Laboratory and Development of Means for Measuring Student Achievement of Some of These Objectives." Dissertation Abstracts, Vol. 28: 5, p. 1732A, 1967a.

Jensen, Gary Dean. "The Development and Evaluation of Some Behavioral Objectives for the Laboratory of a Non-Major College Level Course in General Biology." Dissertation Abstracts, Vol. 33: 12, p. 3115A, 1973.

Johansen, Gerard T. Sr. "Analogue Models in the Laboratory Exercise: One Method for Teaching to Think." Paper presented at the National Association for Research in Science Teaching annual meeting, Boston, MA, April, 1980. (ERIC Document Reproduction Service No. ED 186 253)

Johnson, Lloyd K., E. S. Obourn, and P. E. Blackwood. Research in the Teaching of Science (covers 1959-1963.) Washington, D.C.: U.S. Department of Health Education and Welfare, 1965. (ERIC Document Reproduction Service No. ED 011 844)

Johnson, Philip G., ed. Science Education Research Studies - 1957. Washington, D.C: Office of Education Report No. OE-Circ.-334-111, February, 1952. (ERIC Document Reproduction Service No. ED 011 846)

Johnson, Philip G. Science Education Research Studies - 1952. Washington, D.C.: Office of Education, Report No. OE-334-IV, June, 1953. (ERIC Document Reproduction Service No. ED 011 846)

Johnson, Philip G. "Some Revolutionary Changes in Science Education: 1850-1950," Science Education: Past or Prologue, ed. Robert L. Steiner, p. 118-151. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education, November, 1977. (ERIC Document Reproduction Service No. ED 150 019)

Johnson, Philip G. "Some Developments in Science Teaching and Testing." School Science and Mathematics L(437): 187-199, March, 1950.

Johnson, Roger C. "Three Presentation Modes of Mechanics Experiments in College Physics." Dissertation Abstracts, Vol. 33: 7, p. 3425A, 1973.

Johnson, Roger T., F. L. Ryan, and Helen Schroeder. "Inquiry and the Development of Positive Attitudes," Science Education 58(1): 51-56, 1974.

Jones, James E. "Computer-Simulated Experiments in High School Physics and Chemistry." Dissertation Abstracts, Vol. 33: 8, p. 4200, 1973.

Jungwirth, E., A. Dreyfus, N. Umiel, and J. Broza. "How to Realize the Educational Potential of Laboratory Work in Genetics," Journal of Biological Education 14(1): 29-35, 1980.

Kempa, R. F., and J. E. Ward. "The Effect of Different Modes of Task Orientation on Observational Attainment in Practical Chemistry," Journal of Research in Science Teaching 12(1): 69-76, 1975.

Kent, Richard B. "The Effect of Laboratory Procedure and Ability Grouping on Achievement in an Introductory Chemistry Laboratory." Dissertation Abstracts, Vol. 29: 8, p. 2608A, 1969.

King, Charles R. "Implications of Literature and Comparison of Two Laboratory Teaching Methods in General College Biology for Non-Biology Students: Demonstration Method and the Individual Laboratory Method." Dissertation Abstracts, Vol. 30: 2, p. 621A, August, 1969.

King, Thomas J. "A Study of the Effects of a Traditional and an Audio-tutorial Biology Laboratory on the Attitudes of Junior College Students Toward Biology." Dissertation Abstracts, Vol. 36: 4, p. 2122A, 1975.

Kline, Arlyn A. "A Study of the Relationship Between Self-Directed and Teacher-Directed Eighth Grade Students Involved in an Open-Ended Supplementary ESCP Laboratory Block," Journal of Research in Science Teaching 8(3): 263-271, 1971.

Klopfer, Leopold E. "Evaluation of Learning in Science," Chapter 18, Handbook on Formative and Summative Evaluation of Student Learning, eds. Bloom, B. S., J. T. Hastings, and G. F. Madaus. New York: McGraw-Hill Book Co., 1971.

Klopfer, Leopold E., and William W. Cooley. "The History of Science Cases for High Schools in the Development of Student Understanding of Science and Scientists," Journal of Research in Science Teaching 1: 33-47, 1963.

Klopfer, Leopold E., et al. "History of Science Cases for High Schools Teachers' Guide for Case 3, The Discovery of Bromine." (Mimeographed) 1960.

Kochendorfer, Leonard H. "A Comparative Study of the Classroom Practices and Teaching Rationale of High School Biology Teachers Using Different Curriculum Materials." Dissertation Abstracts, Vol. 27(9): p. 2947A, March, 1967.

Kochendorfer, Leonard H., and Addison E. Lee. "The Development of a Student Checklist to Determine Classroom Teaching Practices in High School Biology." Biological Sciences Curriculum Study. (Mimeographed, no date.)

Koran, John J. Jr. A Summary of Research in Science Education for the Years 1968-1969 College Level. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education, Research Review Series, Science Paper 8, August, 1972. (ERIC Document Reproduction Service No. ED 085 218)

Kruglak, Haym. "Measurement of Laboratory Achievement. Part III. Paper-Pencil Analogs of Laboratory Performance Tests," American Journal of Physics 23: 82-87, 1955.

Kruglak, Haym. "Preparation and Publication of Laboratory Test Items for College Courses in General Physics." Report submitted to the National Science Foundation. Kalamazoo, MI: Western Michigan University, June, 1960.

Kruglak, Haym and Clifford Wall. "Laboratory Performance Tests for General Physics." Kalamazoo, MI: Western Michigan University, 1959.

Kyle, Wm. C. Jr., J. E. Penick, and J. A. Shymansky. "Assessing and Analyzing the Performance of Students in College Science Laboratories." Journal of Research in Science Teaching 16(6): 545-551, 1979.

Lancaster, Otis E. "Do We Believe in Laboratories," Engineering Education 68(4): 289, 294, January, 1978.

Lancy, David F. The Beliefs and Behaviors of Pupils in an Experimental School: The Science Lab. Pittsburgh, PA: University of Pittsburgh, 1976. (ERIC Document Reproduction Service No. ED 127 400)

Lawlor, Elizabeth P. Research in Science Education 1953 through 1957. New York: Teachers College Press, 1970.

Ledbetter, J. C. "The Effects of Instrumentation of Freshman Chemistry Laboratory on Achievement and Interest in Chemistry." Dissertation Abstracts, Vol. 39: 8, p. 3195A, 1970.

Lee, Addison E. "Inventory Evaluation Potential - The BSCS Laboratory Block Program." Austin, TX: Science Education Center. (Mimeographed, no date.)

Lee, Addison E. et al. Research Studies in College Science from July 1963 to July 1964. Austin, TX: University of Texas, Science Education Center, 1965. (ERIC Document Reproduction Service No. ED 011 836)

Lee, Addison E., and Glen E. Peterson, eds. Laboratory Blocks in the Teaching of Biology. Special Publication No. 5. Boulder, CO: Biological Sciences Curriculum Study, 1967.

Lee, Janice T. "The Role of the Laboratory in Introductory College Biology Courses." Dissertation Abstracts, Vol. 39: 5, p. 2855A, 1978.

Lee, Janice T. "The Role of the Laboratory in Introductory College Biology Courses." Unpublished Doctor's dissertation, North Carolina State University, 1978.

Lerch, Robert D. "An Evaluation of the Divergent Physics Laboratory," Science Education 57(2): 153-160, 1973.

Linn, Marcia C., Benjamin, Chen; and Herbert D. Thier. "Personalization in Science: Preliminary Investigation at the Middle School Level." AESOP, Lawrence Hall of Science. Berkeley, CA: University of California. (Mimeographed, no date.)

Lisonbee, Lorenzo, and Bill J. Fullerton. "The Comparative Effect of BSCS and Traditional Biology on Student Achievement." Reprint from School Science and Mathematics, p. 594-598, October, 1964.

Little, Lawrence G., and Rob W. DeM Maclay. "Skills and Skills Tests in Experimental Physics," Research in Science Education 8: 145-156, 1978.

Lucow, William H., and Kenneth E. Anderson. "The Methodology of Educational Research in Science and Mathematics," Review of Educational Research 31(3): 331-340, June, 1961.

Lunetta, Vincent N. and P. Tamir. "An Analysis of Laboratory Activities in Two Modern Science Curricula: Project Physics and PSSC." Paper presented at National Association for Research in Science Teaching annual meeting, Toronto, April, 1978. (ERIC Document Reproduction Service No. ED 184 816)

Lunetta, Vincent N., and P. Tamir. "Matching Lab Activities with Teaching Goals," The Science Teacher 46(5): 22-24, 1979.

Lunetta, Vincent N. "The Design and Evaluation of a Series of Computer Simulated Experiments for Use in High School Physics." Dissertation Abstracts, Vol. 33: 6, p. 2785A, 1972.

Mallinson, George G. "A Summary of Research in Science Education-1975." Special issue of Science Education, New York: John Wiley & Sons, 1976. (ERIC Document Reproduction Service No. ED 148 602)

Mallinson, George G., and Jacqueline V. Buck. "Some Implications and Practical Applications of Recent Research in the Teaching of Science at the Secondary-School Level," Science Education 38(1): 58-81, February, 1954.

Mallinson, Jacqueline B. "What Have Been the Major Emphases in Research in Elementary Science During the Past Five Years?" Science Education 40(3): 206-208, April, 1956.

Mandell, Alan. "A Study of the Effect of Laboratory Experiences Upon Critical Thinking Ability in a College Biology Course." Dissertation Abstracts, Vol. 27: 8, p. 2401A, February, 1967.

Manteufel, Mary S. "A Naturalistic and Experimental Study of the Processes Used by Undergraduate General Biology Students in Formulating and Conducting Investigations." Dissertation Abstracts, Vol. 41(1): p. 189A, July, 1980.

Marlow, Loran D. "The Development and Assessment of an Audio-Visual Tutorial Laboratory Program Serving College-Level Introductory Earth Science." Dissertation Abstracts, Vol. 34: 9, p. 5993A, 1974.

Matala, Dorothy C., and C. G. McCollum. "Science in the Elementary Grades," Review of Educational Research 27(4): 311-328, October, 1957.

Mayer, William V. Biology Teachers' Handbook, 3rd edition. New York: John Wiley & Sons, 1978.

McClurgh, James E. "The Development and Experimental Evaluation of an Open-Scheduled Auto-Tutorial Geology Laboratory." Dissertation Abstracts, Vol. 32: 3, p. 1358A, 1971.

McDermott, Lillian C., L. K. Piternick, and M. L. Rosenquist. "Helping Minority Students Succeed in Science, II. Implementation of a Curriculum in Physics and Biology," Journal of College Science Teaching p. 201-205, March, 1980.

McKeachie, W. J. "Research on Teaching at the College and University Level," Handbook of Research on Teaching, ed. N. L. Gage. Chicago: Rand McNally & Co., 1963.

McKinnon, Joe W. "Encouraging Logical Thinking in Selected Pre-Engineering Students," Engineering Education 66(7): 740-744, April, 1976.

Meder, Elsa M. "The Science Curriculum," Review of Educational Research 21(4): 249-263, October, 1951.

Michels, Walter C. "The 'Open Ended' Laboratory--Its Successes and Problems." Remarks from a panel discussion at Michigan State University, Oakland, February 10, 1962. NSF Archives title document. (Mimeographed.)

Miles, Vaden W., and W. C. Van Deventer. "The Teaching of Science at the College and University Level." Review of Educational Research 31(3): 305-313, June, 1961.

Miller, Dorothy D. "The Effect of an Experimental Approach to Science Instruction on the Achievement of Certain Sixth Grade Students." Dissertation Abstracts, Vol. 28: 4, p. 1212A, 1967.

Milson, James L. "Evaluation of the Effect of Laboratory-Oriented Science Curriculum Materials on the Attitudes of Students with Reading Difficulties," Science Education 63(1): 9-14, 1979.

Mitchell, D. A. "The Production of Criteria for Evaluating Science Curriculum Materials with Specific Reference to Criteria for Inquiry and the Application of these Criteria to Chemistry Curriculum Materials," Research in Science Education 8: 59-69, 1978.

Mitchell, Donald W. "A Comparative Study of Auto-Tutorial and Conventional Laboratory Approaches in College Biology." Dissertation Abstracts, Vol. 32: 4, p. 1882A, 1971.

Montean, John and John Butzow. A Summary of Research in Science Education for the Years of 1965-1967, College Level. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education Review Series. Science Paper 8, March, 1970. (ERIC Document Reproduction Service No. ED 062 214)

Moyer, Albert E. "Edwin Hall and the Emergence of the Laboratory in Teaching Physics," The Physics Teacher 14(2): 96-103, February, 1976.

Murphy, Glenn W. "A Study of the Relative Effectiveness of Content and Process Centered Biology Laboratories for College Freshmen." Dissertation Abstracts, Vol. 31: 4, p. 1587A, 1970.

Namek, Yakub R. "The Effect of Integrated Laboratory Work on Achievement in Secondary School Chemistry." Dissertation Abstracts, Vol. 28: 11, p. 4538A, 1968.

Napier, Edgar C. "A Laboratory Method of Instruction for Teaching Biology to Disadvantaged Southern Youth." Dissertation Abstracts, Vol. 30: 6, p. 2262A, 1969.

National Association of Secondary-School Principals. "Science in Secondary Schools Today." The Bulletin of the National Association of Secondary-School Principals, 37(191): 6-207, January, 1953.

National Catholic Educational Association. "Teaching Science in the Catholic High School" 22(2), July, 1964. Catholic High School Quarterly Bulletin.

National Science Foundation. Early Adolescence Perspectives and Recommendations to the National Science Foundation. Washington, D.C.: National Science Foundation, September, 1978. (ERIC Document Reproduction Service No. ED 168 900)

National Science Teachers Association, Committee on Curriculum Studies: K-12. "School Science Education for the 70's," The Science Teacher p. 46-50, November, 1971.

Newman, Robert L. "A Focus on Problems of National Interest in the College General Chemistry Laboratory: The Effects of the Problem-Oriented Method Compared with those of the Traditional Approach." Dissertation Abstracts, Vol. 33: 11, p. 6068A, 1973.

Niedfeldt, Kenneth H. "Comparison of the Effectiveness of Two Types of Laboratory Activities in High School Chemistry Classes Using the CHEM Program." Dissertation Abstracts, Vol. 29: 12, p. 4387A, 1969.

Novak, Joseph D. A Summary of Research in Science Education-1972. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education. December, 1973. (ERIC Document Reproduction Service No. ED 090 055)

Obourn, Ellsworth S. et al. "Fifth Annual Review of Research in Science Science Education 41(5): 375-411, December, 1957.

Obourn, Ellsworth S., and Clarence H. Boeck. "Sixth Annual Review of Research in Science Teaching." Science Education 44(5): 374-399, December, 1960.

Obourn, Ellsworth S., P. E. Blackwood, and M. J. McKibben. Research in the Teaching of Science, July 1957-July 1959. Washington, D.C.:

U. S. Department of Health Education and Welfare, 1962. (ERIC Document Reproduction Service No. ED 011 835)

Office of Scientific Personnel. Guidelines for Development of Programs in Science Instruction. Washington, D.C.: National Academy of Sciences, National Science Research Council, 1963. (ERIC Document Reproduction Service No. ED 011 001)

Osborne, Roger. "Using Student Attitudes to Modify Instruction in Physics," Journal of Research in Science Teaching 13(6): 525-531, 1976.

Packard, Harry B. "The Design and Analysis of Laboratory Experiences for High School Physics." Dissertation Abstracts, Vol. 23: 12, p. 4623, 1963.

Palmer, Ray A. "The Development of Selected Concepts by Students in BSCS Biology." Dissertation Abstracts, Vol. 27: 11, p. 3782A, May, 1967.

Parakh, Jal S. "Verbal Pupil-Behavior Category System," Mirrors for Behavior II, eds. Anita Simon and E. Gil Boyer. Philadelphia, PA: Classroom Interaction Newsletter c/o Research for Better Schools, Inc., pp. 62-1 - 62-5, 1970. (ERIC Document Reproduction Service No. ED 042 937)

Paulsen, Maryanne A. "Effects of Three Instructional Approaches (Lecture-Only, Lecture-Laboratory, and Lecture-Delayed Laboratory) on Community College Students' Achievement in a General Education Environmental Science Program," Dissertation Abstracts, Vol. 39: 9, p. 5358A, March, 1979.

Pella, Milton O. "The Laboratory and Science Teaching." The Science Teacher 28(5): 29-31, September, 1961.

Pella, Milton O., and Jack Sherman. "A Comparison of Two Methods of Utilizing Laboratory Activities in Teaching the Course IPS," School Science and Mathematics 69(4): 303-314, April, 1969.

Peterson, Rita, and Gaylen R. Carlson. "A Summary of Research in Science Education-1977." Special issue of Science Education, New York: John Wiley & Sons, 1978.

Pickering, Miles. "Are Lab Courses a Waste of Time?" From column entitled "Point of View," The Chronicle of Higher Education p. 80, February 19, 1980.

Platts, C. V. "Recording Science Lessons on Cine Film and the Analysis of Such Records," School Science Review 58(202): 5-11, September, 1976.

Powers, Samuel R. "Science," Review of Educational Research 5(1): 70-74, February, 1935.

Powers, Samuel R. "Science," Review of Educational Research 8(1): 60-66, February, 1938.

Powers, Samuel R., and David J. Blick. "Teaching of Science in Senior High School and Junior College." Review of Educational Research 15(4): 301-309, October, 1945.

Powers, Samuel R., and Vivian Edmiston. "Overview of the Period," Review of Educational Research 12(4): 363-368, October, 1942.

Pringle, Rhodell, and Ashley G. Morgan. "The Effects of Laboratory-Oriented Experiences in SCIS on the Stability of Cognitive Style of Teachers," Journal of Research in Science Teaching 15(1): 47-51, 1978.

Raghubir, Karran. "The Laboratory-Investigative Approach to Science Instruction," Journal of Research in Science Teaching 16(1): 13-17, 1979.

Rainey, Robert G. "The Effects of Directed Versus Non-Directed Laboratory Work on High School Chemistry Achievement." Dissertation Abstracts, Vol. 24: 1, p. 146A, 1963.

Ramsey, Gregor A., and R. W. Howe. "An Analysis of Research Related to Instructional Procedures in Elementary School Science," Science and Children pp. 25-36, April, 1969a.

Ramsey, Gregor A., and R. W. Howe. "An Analysis of Research on Instructional Procedures in Secondary School Science, Part I - Outcomes of Instruction," The Science Teacher pp. 62-70, March, 1969a.

Ramsey, Gregor A., and R. W. Howe. "An Analysis of Research on Instructional Procedures in Secondary School Science, Part II - Instructional Procedures." The Science Teacher pp. 72-81, April, 1969c.

Rasmussen, F. A. "Matching Laboratory Activities with Behavioral Objectives," Biological Science 20(5): 292-294, March 1, 1970.

Reach, Roy W. "A Comparison of Two Methods of Conducting a Basic Circuit Analysis Engineering Technology Laboratory Course in an Ohio Two-Year Technical College." Dissertation Abstracts, Vol. 38(5): 2531A, November, 1977.

Reif, F., and M. St. John. "Teaching Physicists' Thinking Skills in the Laboratory." American Journal of Physics 47(11): 950-957, November, 1979.

Renner, John W., M. R. Abraham, and D. G. Stafford. "A Summary of Research in Science Education-1976." Special issue of Science Education, New York: John Wiley & Sons, 1977. (ERIC Document Reproduction Service No. ED 157 798)

Rentoul, A. J., and B. J. Fraser. "Measuring Perceptions of Inquiry and Open Learning Environments," Research in Science Education 8: 79-88, 1978.

Requa, Lyle K. "An Analysis of Two Methods of Teaching Biological Sciences Laboratory." Dissertation Abstracts, Vol. 27: 12, p. 4173A, 1967.

Richardson, John S. et al. "Materials in the Teaching of Science." Review of Educational Research 21(4): 279-289, October, 1951.

Richardson, John S., and J. Darrell Barnard. "Methods and Materials in the Teaching of Science." Review of Educational Research 18(4): 323-336, October, 1948.

Richmond, P. E. "Who Needs Laboratories?" Physics Education 14(6): 349-350, September, 1979.

Robertson, Harold F. "A Study of the Effect Introductory Physical Science Produces in Students' Abilities in Selected Areas of Physics." Dissertation Abstracts, Vol. 33: 4, p. 1542, October, 1972.

Robinson, James T. "Evaluating Laboratory Work in High School Biology," The American Biology Teacher 31: 236-240, April, 1969.

Robinson, James T. "Philosophical and Historical Bases of Science Teaching." Review of Educational Research 39(4): 459-472, October, 1969.

Rogers, Ralph. "A Comparison of Two Methods of Science Instruction in a College General Studies Program: A Laboratory-Centered Approach and a Group Discussion Approach." Dissertation Abstracts, Vol. 32: 8, p. 4252, February, 1972.

Rosen, Sidney. "A History of the Physics Laboratory in the American Public High School (to 1910)," American Journal of Physics 22: 194-204, 1954.

Ross, Jean F. "Genetics Instruction. Audio-Tutorial Laboratory Approach Compared to Traditional Methods." Dissertation Abstracts, Vol. 39: 1, p. 212A, 1978.

Rowbotham, Noel D. "The Comparison of an Auto-Tutorial Laboratory and a Traditional Laboratory in Physical Science." Dissertation Abstracts, Vol. 30: 7, p. 2730A, 1970.

Rowe, Mary Budd, ed. What Research Says to the Science Teacher, Vol. I. Washington, D.C.: National Science Teachers Association, 1978.

Rowe, Mary Budd, and Linda DeTure. "A Summary of Research in Science Education 1973." Special issue of Science Education, New York: John Wiley & Sons, 1974. (ERIC Document Reproduction Service No. ED 113 140)

Rowsey, Robert E. "A Comparative Study of Two Methods of Instruction in a University Animal Biology Course: Audio-Tutorial with Conventional Lecture-Laboratory." Dissertation Abstracts, Vol. 34: 6, p. 3182A, 1973.

Rozolis, James T. "A Comparison of Traditional High School Biology Courses and the Biological Sciences Curriculum Study Program of Courses," Bioscience pp. 315-323, May, 1967.

Sagness, Richard L. "A Study of Selected Outcomes of a Science Pre-Service Teacher Education Project Emphasizing Early Involvement in Schools of Contrasting Environmental Settings." Unpublished Doctor's dissertation, The Ohio State University, 1970. (ERIC Document Reproduction Service No. ED 052 994)

Saunders, W. L., and D. H. Dickinson. "A Comparison of Community College Students' Achievement and Attitude Changes in a Lecture-Only and Lecture-Laboratory Approach to General Education Biological Science Courses," Journal of Research in Science Teaching 16(5)" 459-464, 1979.

Schwab, Joseph J. "The Teaching of Science as Enquiry." The Teaching of Science, Cambridge, MA: Harvard University Press, 1964.

Science Education: Accomplishment and Needs, A Working Paper. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education, December, 1978. (ERIC Document Reproduction Service No. ED 171 571)

Seal, Charles W. "Two Methods of Teaching a General Biology Course in a Community College: Audio-Tutorial with Conventional Lecture-Laboratory." Dissertation Abstracts, Vol. 37: 9, p. 5729A, 1977.

Serlin, Ronald C. "The Effects of a Discovery Laboratory on the Science Process, Problem-Solving, and Creative Thinking Abilities of Undergraduates." Dissertation Abstracts, Vol. 37: 9, p. 5729, 1977.

Shaver, Paul M. "A Study of the Effectiveness of an Independent Study Program for a Beginning Course in Earth Science." Dissertation Abstracts, Vol. 31: 1, p. 310A, 1970.

Sherman, Jack E. "The Relative Effectiveness of Two Methods of Utilizing Laboratory-Type Activities in Teaching Introductory Physical Science." Dissertation Abstracts, Vol. 29: 12, p. 4391A, 1969.

Sherman, Jack E. "The Relative Effectiveness of Two Methods of Utilizing Laboratory-Type Activities in Teaching Introductory Physical Science." Technical Report No. 65. Madison, WI: University of Wisconsin. Wisconsin Research & Development Center for Cognitive Learning, November, 1968.

Shulman, Lee S., and Evan R. Keislar. Learning By Discovery: A Critical Appraisal. Chicago: Rand McNally & Co., 1966. (ERIC Document Reproduction Service No. ED 015 504)

Shulman, Lee S., and Pinchas Tamir. "Research on Teaching in the Natural Sciences," in Second Handbook of Research on Teaching, ed. Robert M. W. Travers. Chicago: Rand McNally & Co., 1973.

Shymansky, James A., and John E. Penick. "Use of Systematic Observations to Improve College Science Laboratory Instruction," Science Education 63(2): 195-203, 1979.

Simon, Anita, and E. Gil Boyer. Mirrors for Behavior II. Volumes A and B. Philadelphia, PA: Classroom Interaction Newsletter c/o Research for Better Schools, Inc., 1970. (ERIC Document Reproduction Service No. ED 042 937

Simpson, Faril. "The Effect of the Laboratory in Achieving General Education Objectives in a College Physical Science Course." Dissertation Abstracts, Vol. 30(7): 2915A, January, 1970.

Simpson, Joyce K., and Jerry L. Gallentine. "Representational Versus Analytic Drawings in the Laboratory," The American Biology Teacher 33(7): 419-420, October, 1971.

Smith, Alden E. "An Experimental Study of the Use of an Extended Laboratory Problem in Teaching College General Biology to Non-Majors." Dissertation Abstracts, Vol. 32: 3, p. 1403A, 1971.

Smith, Herbert A., and Guy B. Homman. "The Academic and Professional Preparation of Teachers of Science." Review of Educational Research 31(3): 289-295, June, 1961.

Smith, Herbert A., and Nathan S. Washton. "Science in the Secondary Schools." Review of Educational Research 27(4): 343-355, October, 1957.

Smith, Herbert E., et al. "Third Annual Review of Research in Science Teaching." Science Education 39(5): 335-356, December, 1955.

Smith, Melvin O. "A Comparison of Two Laboratory Methods for the Teaching of General Physical Science at the College Level: Vicarious Experimentation Versus Conventional Experimentation." Dissertation Abstracts, Vol. 32: 9, p. 5116, 1972.

Snyder, Jack R. "Effect of Adding the Problem Solving Project Technique to a Lecture Laboratory Method in Teaching College Biology." Dissertation Abstracts, Vol. 21: 9, p. 2639A, 1961.

Sorensen, LaVar L. "Change in Critical Thinking Between Students in Laboratory-Centered and Lecture-Centered Patterns of Instruction in High School Biology." Dissertation Abstracts, Vol. 26: 11, p. 6567A, 1966.

Spears, Jacqueline, and Dean Zollman. "The Influence of Structured Versus Unstructured Laboratory on Students' Understanding the Process of Science," Journal of Research in Science Teaching 14(1): 33-38, 1977.

Spreadbury, Wendall N. "A Comparison of Three Methods of Instruction in Science Relative to the Interpretation of Experimental Data." Dissertation Abstracts, Vol. 30: 3, p. 1058A, 1969.

Stake, Robert E., Jack Easley, et al. Case Studies in Science Education Volume I: The Case Reports. Washington, D.C.: U. S. Government Printing Office. Science Education No. 78-74, 1978a. (ERIC Document Reproduction Service No. ED 166 058)

Stake, Robert E., Jack Easley, et al. Case Studies in Science Education Volume II: Design, Overview and General Findings. Washington, D.C.: U. S. Government Printing Office, 1978b. (ERIC Document Reproduction Service No. ED 166 059)

Stake, Robert and Jack Easley. "Case Studies in Science Education Executive Summary (Chapter 19), in The Status of Pre-College Science, Mathematics, and Social Studies Educational Practices in U.S. Schools: An Overview and Summaries of Three Studies. Washington, D.C.: U.S. Government Printing Office, July, 1978c.

Steele, Robert W. "Development and Evaluation of an Individualized Self-Paced Physics Course for Non-Science Majors." Dissertation Abstracts, Vol. 35: 7, pp. 4274-4275A, 1975.

Stekel, Frank D. "Development of a More Flexible Physical Science Laboratory Program for Non-Science Majors with Superior High School Science Backgrounds." Whitewater, Wisconsin State University Whitewater. The Wisconsin State Universities Consortium of Research Development, June, 1969. (ERIC Document Reproduction Service No. ED 053 987)

Stekel, Frank D. "The Effects of Increasing the Student Involvement in a College Physical Science Laboratory Program." Dissertation Abstracts, Vol. 31: 1, p. 5880A, 1971.

Stollberg, Robert and Theodore Benjamin. Planning for Excellence in High School Science. Washington, D.C.: National Science Teachers Association, 1961.

Strehle, Joseph A. "The Comparative Achievement of Seventh Grade Exploratory Science Students Taught by Laboratory Versus Enriched Lecture-Demonstration Methods of Instruction." Dissertation Abstracts, Vol. 25: 4, p. 2386, 1964.

Stuit, Dewey B., and Max D. Engelhart. "A Critical Summary of the Research on the Lecture-Demonstration Versus the Individual-Laboratory Method of Teaching High School Chemistry," Science Education 16(5): 380-391, October, 1932.

Sullivan, Daniel J. "An Exploratory Study of Specific Psychomotor Abilities in Selected Secondary Science Laboratory Oriented Class rooms of Detroit, Michigan." Dissertation Abstracts, Vol. 33: 5, p. 2090, 1972.

Sund, Robert B., and Leslie W. Trowbridge. Teaching Science by Inquiry. Columbus, OH: Charles E. Merrill Books, Inc., 1967.

Sundberg, Randell L. "The Effectiveness, Upon Students Majoring in Elementary Education, of Three Different Experimental Problem-Solving Processes for the College Physics Laboratory." Dissertation Abstracts, Vol. 32: 1, p. 270A, 1971.

Sutton, Traver C. "Laboratory Work is Essential," School Science and Mathematics XLIX(430): 351-358, May, 1949.

Swift, J. Nathan. Research in Science Education 1948 through 1952. New York: Teachers College Press, 1969.

Tamir, Pinchas. "How are Laboratories Used?" Journal of Research in Science Teaching 14(4): 311-316, 1977.

Tamir, Pinchas. "The Role of the Laboratory in Science Teaching." Technical Report No. 10. Iowa City, IA: The University of Iowa, November, 1976.

Tamir, Pinchas. "Nurturing the Practical Mode in Schools," School Review 83: 499-506, May, 1975.

Tamir, Pinchas. "The Practical Mode - A Distinct Mode of Performance in Biology," Journal of Biological Education 6: 175-182, 1972.

Tamir, Pinchas, and F. Glassman. "A Practical Examination for BSCS Students: A Progress Report," Journal of Research in Science Teaching 8(4): 307-315, 1971.

Taylor, Wayne, et al. Review of Research Studies in Science Education. East Lansing, MI: Michigan State University, 1966. (ERIC Document Reproduction Service No. ED 021 235)

Thornton, John W. The Laboratory: A Place to Investigate. Washington, D.C.: Commission on Undergraduate Education in the Biological Science, Publication No. 33, April, 1972. (ERIC Document Reproduction Service No. ED 064 112)

Thorsland, Martin N. "Formative Evaluation in an Audio-Tutorial Physics Course with Emphasis on Intuitive and Analytic Problem Solving Approaches." Dissertation Abstracts, Vol. 32: 9, p. 4931A, 1972.

Toohey, Jack V. "The Comparative Effects of Laboratory and Lecture Methods of Instruction in Earth Science and General Science Classes." Dissertation Abstracts, Vol. 24: 8, p. 3247, 1964.

Townes, James H. "An Experimental Comparison of Two Laboratory Approaches for Teaching General Physical Science at the College Level: Vicarious Laboratory Method and Conventional Laboratory Method." Dissertation Abstracts, Vol. 36: 11, p. 7176A, 1976.

Travers, Robert M. W. ed. Second Handbook of Research on Teaching. Chicago: Rand McNally & Co., 1973.

Trowbridge, Leslie W., J. R. Anderson, and J. E. Rahn. A Summary of Research in Elementary, Secondary, and College Levels of Science Education for 1970. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education, Research Review Series. Science Paper 9, September, 1972. (ERIC Document Reproduction Service No. ED 085 219)

Tyler, Ralph W., and Sheldon H. White. Testing, Teaching and Learning. Washington, D.C.: U. S. Department of Health, Education and Welfare, and National Institute of Education, October, 1979. (ERIC Document Reproduction Service No. ED 181 080)

Uricheck, Michael J. "The Effect of Verbal Interaction on the Achievement of Specific Skills in the Introductory College Chemistry Laboratory." Dissertation Abstracts, Vol. 32: 3, p. 1362A, 1971.

Vander Wal, Judson M. "The Relationships Between Two Methods of Teaching College Biology in Achievement and Attitude." Dissertation Abstracts, Vol. 34: 1, p. 215A, 1973.

Van Deventer, W. C. "The Teaching of Science at the College and University Level." Review of Educational Research 34(3): 334-346, June, 1964.

Venkatachelam, Chaya, and R. W. Rudolph. "Cookbook Versus Creative Chemistry," Journal of Chemical Education 51(7): 479-482, July, 1974.

Walberg, Herbert J., and Gary T. Anderson. Learning Environment Inventory (1967-68 Edition). Cambridge, MA: Harvard University, Harvard Project Physics, 1968. (ERIC Document Reproduction Service No. ED 131 997)

Walsh, Robert G. "The Keller Plan in College Introductory Physical Geology: A Comparison with the Conventional Teaching Method." Dissertation Abstracts, Vol. 37: 7, p. 4257A, 1977.

Ward, Charles R. "Designing General Chemistry Laboratory Experiments for the Enhancement of Cognitive Development." Dissertation Abstracts, Vol. 39: 9, p. 5424A, 1979.

Watson, Fletcher G. "Research on Teaching Science," Handbook of Research on Teaching, ed. N. L. Gage. Chicago: Rand McNally & Co., 1963.

Weiss, Iris R. Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education. Washington, D.C.: U. S. Government Printing Office. Science Education No. 78-72, 1978. (ERIC Document Reproduction Service No. ED 152 565)

Welch, Wayne A. A Long Term Study of the Stability of Learning Environments. Research Paper No. 6. Minneapolis, MN: The University of Minnesota, November, 1977. (ERIC Document Reproduction Service No. ED 161 685)

Welch, Wayne W. "The Development of an Instrument for Inventorying Knowledge of the Processes of Science." (Mimeographed, no date.)

Welch, Wayne W. Review of the Research and Development Program of Harvard Project Physics. Columbus, OH: ERIC Clearinghouse for Science Education, Mathematics and Environmental Education, Occasional Paper Series. Science Paper, December, 1971b. (ERIC Document Reproduction Service No. ED 059 887)

Welch, Wayne W. Five Years of Evaluating Federal Programs--Implications for the Future. Research Paper No. 22, Minnesota Research and Evaluation Project, College of Education. Minneapolis, MN: The University of Minnesota, April, 1976.

Welch, Wayne W. A Summary of Research in Science Education for the Years of 1968-1969, Secondary School Level. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education, Research Review Series. Science Paper 7, June, 1971a. (ERIC Document Reproduction Service No. ED 052 051)

Westmeyer, Paul, William R. Snyder, and William S. LaShier, Jr. A Summary of Research in Science Education for the Years 1965-1967, Secondary Level. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education, Research Review Series. Science Paper 1, September, 1969. (ERIC Document Reproduction Service No. ED 035 775)

What are the Needs in Precollege Science, Mathematics, and Social Science Education? Views from the Field. Washington, D.C.: National Science Foundation. Science Education No. 80-9, 1980. (ERIC Document Reproduction Service No. ED 193 051)

Wheatley, John H. "A Scheme for Evaluating the Audio-Tutorial Biology Laboratory in the Cognitive and Affective Domains." Dissertation Abstracts, Vol. 33: 9, p. 4971A, 1973.

Wheeler, Betty L. et al. "Research in Science Teaching at the Elementary Grade Levels." Science Education 46(2): 133-139, March, 1962.

White, Richard T. "Relevance of Practical Work to Comprehension of Physics," Physics Education 14(6): 384-387, September, 1979.

Whitney, Chester B. "The Effect of General College Physics Laboratory Instruction on Selected Student Non-Academic Characteristics." Dissertation Abstracts, Vol. 26:6, p. 3198A, December, 1965.

Whitten, Maurice M. "Changes in Understanding of the Nature of Science and in Critical Thinking Resulting from Two Different Physical Science Courses." Dissertation Abstracts, Vol. 32: 3, 1363A, 1971.

Wilbur, Norma J. L. "The Science Laboratory as a Learning Environment: An Exploratory Investigation." Dissertation Abstracts, Vol. 38: 3, p. 1262A, 1977.

Woodburn, John H., and Ellsworth S. Obourn. Teaching the Pursuit of Science. New York: The MacMillan Co., 1965.

Yager, Robert E., Harold B. Engen, and Bill C. F. Snider. "Effects of the Laboratory and Demonstration Methods Upon the Outcomes of Instruction in Secondary Biology," Journal of Research in Science Teaching 6: 76-86, 1969.

Yett, James W., and Joseph F. X. McCarthy. "Do High School Chemistry Students Really Learn Lab Skills?" Journal of College Science Teaching pp. 100-101, November, 1977.

Yett, James William Jr. "Relationship Between Success in General College Chemistry Laboratory and Secondary School Chemistry Laboratory Experience." Dissertation Abstracts, Vol. 37: 2, p. 905, 1976.

Zingaro, Joseph S. "An Experimental Comparison Between Two Methods of Teaching College Sophomores the Interrelationship of Physicochemical Principles in Physical Science." Dissertation Abstracts, Vol. 27: 4, p. 1004A, 1966.